U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: STANDARDIZED METHOD OF REPORTING AIRPORT PAVEMENT STRENGTH - PCN

Date: **DATE**, DRAFT
Initiated by: AAS-100

AC No: 150/5335-5A
Change:

1. THE PURPOSE OF THIS ADVISORY CIRCULAR.
This advisory circular (AC) provides guidance for using the standardized International Civil Aviation Organization (ICAO) method to report airport pavement strength. The standardized method is known as the ACN/PCN method.

2. WHAT THIS AC CANCELS.
This AC cancels AC 150/5335-5, Standardized Method of Reporting Airport Pavement Strength – PCN, dated 6/15/83.

3. WHO THIS AC AFFECTS.
Member countries of ICAO are required to report pavement strength information for a variety of purposes. The ACN/PCN method has been developed and adopted as an international standard and has proven to facilitate the exchange of pavement strength rating information. This AC provides specific guidance on how to report airport pavement strength using the standardized method.

4. RELATED READING MATERIAL. The publications listed in appendix 1 provide further information on the development and use of the ACN/PCN method.

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CHAPTER 1. INTRODUCTION

1.0 BACKGROUND. The United States is a member of the International Civil Aviation Organization (ICAO) and is bound by treaty agreements to comply with the requirements of ICAO to the maximum extent practical (see FAA Order 2100.13, FAA Rulemaking Policies, Chapter 11). Annex 14 to the Convention of International Civil Aviation - Aerodromes requires that each member country publish information on the strengths of all public airport pavements in its own Aeronautical Information Publication (AIP). Pavement strength information is reported by the FAA in the Airport Master Record (5010 Database) and the Airport/Facility Directory (AFD).

1.1 DEVELOPMENT OF A STANDARDIZED METHOD. In 1977 the ICAO established a Study Group to develop a single international method of reporting pavement strengths. The study group developed and ICAO adopted the Aircraft Classification Number - Pavement Classification Number (ACN-PCN) method. Using this method, it is possible to express the effect of individual airplane on different pavements by a single unique number which varies according to pavement type and subgrade strength. This number is the Aircraft Classification Number (ACN). Conversely, the load carrying capacity of a pavement can be expressed by a single unique number, without specifying a particular airplane or detailed information about the pavement structure. This number is the Pavement Classification Number (PCN).

a. Definition of ACN. ACN is defined as a number which expresses the relative effect of an airplane on a pavement structure for a specified standard subgrade strength.

b. Definition of PCN. PCN is a number which expresses the load carrying capacity of a pavement for unrestricted operations.

c. System Methodology. The ACN-PCN system is structured so that a pavement with a particular PCN value can support, without weight restrictions, an airplane which has an ACN value equal to or less than the pavement's PCN value. This is possible because ACN and PCN values are computed using the same technical basis.

1.2 APPLICATION. The use of the standardized method of reporting pavement strength applies only to pavements with bearing strengths of 12,500 pounds (5 700 kg) or greater. The method of reporting pavement strength for pavements of less than 12,500 pounds (5 700 kg) bearing strength remains unchanged.

1.3 LIMITATIONS OF THE ACN-PCN SYSTEM. The ACN-PCN system is only intended as a method of reporting relative pavement strength to provide airport operators a means to evaluate acceptable operations of airplanes. It is not intended as a pavement design or pavement evaluation procedure, nor does it restrict the methodology used to design or evaluate a pavement structure.

Chapter 2 DETERMINATION OF AIRCRAFT CLASSIFICATION NUMBER

2.0 DETERMINATION OF THE ACN. Official computation of an ACN value is provided by the airplane manufacturer. Computation of the ACN requires detailed information on the operational characteristics of the airplane such as maximum aft center of gravity, maximum ramp weight, wheel spacing, tire pressure, etc.

2.1 SUBGRADE CATEGORY. The ACN-PCN method adopts four standard levels of subgrade strength for rigid pavements and four levels of subgrade strength for flexible pavements. These standard support conditions are used to represent a range of subgrade conditions as shown in Tables 2-1 and 2-2.

Table 2-1. Standard Subgrade Support Conditions for Rigid Pavement ACN Calculation

Subgrade Strength Category	Subgrade Support k-Value pci (MN/m^3)	Represents pci (MN/m^3)	Code Designation
High	552.6 (150)	k ≥ 442 (≥120)	A
Medium	294.7 (80)	221<k<442 (60<k<120)	B
Low	147.4 (40)	92<k≤221 (25<k≤60)	C
Ultra Low	73.7 (20)	k≤92 (≤25)	D

Table 2-2. Standard Subgrade Support Conditions for Flexible Pavement ACN Calculation

Subgrade Strength Category	Subgrade Support CBR-Value	Represents	Code Designation
High	15	CBR ≥ 13	A
Medium	10	8<CBR<13	B
Low	6	4<CBR≤8	C
Ultra Low	3	CBR≤4	D

2.2 OPERATIONAL FREQUENCY. Operational frequency is defined in terms of coverages which represents a full load application on a point in the pavement. Coverages must not be confused with other common terminology used to reference movement of airplanes. As an airplane moves along a pavement section it seldom travels in a perfectly straight path or along the exact same path as before. This movement is known as airplane wander and is assumed to be modeled by a statistically normal distribution. As the airplane moves along a taxiway or runway, it may take several trips or passes along the pavement for a specific point on the pavement to receive a full load application. It is easy to observe the number of passes an airplane may make on a given pavement but the number of coverages must be mathematically derived based upon the established pass-to-coverage ratio for each airplane.

2.3 RIGID PAVEMENT ACN. For rigid pavements, the airplane landing gear flotation requirements are determined by the Westergaard solution for a loaded elastic plate on a Winkler foundation (interior load case), assuming a concrete working stress of 399 psi (2.75 MPa).

2.4 FLEXIBLE PAVEMENT ACN. For flexible pavements, airplane landing gear flotation requirements are determined by the California Bearing Ratio (CBR) method for each subgrade support category. The CBR method employees a Boussinesq solution for stresses and displacements in a homogeneous, isotropic elastic half-space. To standardize the ACN calculation and to remove operational frequency from the relative rating scale, the ACN-PCN method specifies that ACN values be determined at a frequency of 10,000 coverages.

2.5 ACN CALCULATION. Using the parameters defined for each type of pavement section, a mathematically derived single wheel load is calculated to define the landing gear/pavement interaction. The derived single wheel load implies equal stress to the pavement structure and eliminates the need to specify pavement thickness for comparative purposes. This is achieved by equating the thickness derived for a given airplane landing gear to the thickness derived for a single wheel load at a standard tire pressure of 18l psi (1.25 MPa). The ACN is defined as two times the derived single wheel load (expressed in thousands of kilograms).

2.6 VARIABLES INVOLVED IN DETERMINATION OF ACN VALUES. Because airplanes can be operated at various weight and center of gravity combinations, ICAO adopted standard operating conditions for determination of ACN values. The ACN is to be determined at the weight and center of gravity combination that creates the maximum ACN value. Tire pressures are assumed to be those recommended by the manufacturer for the noted conditions. Airplane manufacturers publish maximum weight and center of gravity information in their Airplane Characteristics for Airport Planning (ACAP) manuals.

CHAPTER 3 DETERMINATION OF ACN VALUES USING COMFAA

3.0 ANNOUNCEMENT OF COMFAA SOFTWARE APPLICATION. To facilitate the use of the ACN-PCN system, the FAA has developed a software application that will calculate ACN values using the procedures and conditions specified by ICAO. The software is called COMFAA and it may be downloaded along with its source code and supporting documentation from the FAA website. The program is useful for determining an ACN value under various conditions however the user is reminded that official ACN values are provided by the airplane manufacturer.

3.1 ORIGIN OF THE COMFAA PROGRAM. Appendix 2 of the ICAO, Aerodrome Design Manual, Part 3 Pavements, provides procedures for determining the Aircraft Classification Number (ACN). The appendix provides program code for two FORTRAN software applications capable of calculating the ACN for various airplanes on rigid and flexible pavement systems. The computer program listings in Appendix 2 of the ICAO manual were optically scanned and the FORTRAN code translated into Visual Basic 6.0 for incorporation into COMFAA.

3.2 COMFAA PROGRAM. The COMFAA software is a general-purpose program that operates in two computational modes: ACN Computation Mode and Pavement Thickness Mode.

a. In ACN computation mode COMFAA:
   - Calculates the ACN number for airplanes on flexible pavements.
   - Calculates the ACN number for airplanes on rigid pavements.
   - Calculates flexible pavement thickness based on the ICAO procedure (CBR method) for default values of CBR (15, 10, 6, and 3).
   - Calculates rigid pavement slab thickness based on the ICAO procedures (Portland Cement Association method, interior load case) for default values of k (552.6, 294.7, 147.4, and 73.7 lb/in3 [150, 80, 40, and 20 MN/m3]).

   Note: Thickness calculation in the ACN mode is for specific conditions identified by ICAO for determination of ACN. For flexible pavements a standard tire pressure of 181 psi (1.25 MPa) and 10,000 coverages is specified. For rigid pavements an allowable stress level of 399 psi is identified by ICAO. These parameters seldom represent actual design criteria used for pavement design. The thickness calculated in ACN mode has little meaning to pavement design requirements and should not be used for determining allowable pavement loading.

b. In Pavement Thickness Mode COMFAA:
   - Calculates total flexible pavement thickness based on the FAA CBR method specified in AC 150/5320-6D for CBR values and coverage levels specified by the user.
   - Calculates rigid pavement slab thickness based on the FAA Westergaard method (edge load analysis) specified in AC 150/5320-6D for k values and coverage levels specified by the user.

3.3 INTERNAL AIRPLANE LIBRARY. COMFAA contains an internal library of airplanes covering most large commercial and US military airplanes currently in operation. The internal library is based on airplane information provided directly by airplane manufacturers or obtained from Airplane Characteristics for Airport Planning Manuals. The default characteristics of airplanes in the internal library represent the ICAO standard conditions for calculation of ACN. These characteristics include center of gravity at the maximum aft position for each airplane in the ACN mode, whereas the pavement thickness mode center of gravity is fixed to distribute 95% of the max gross load to the main landing gear for all airplanes.

3.4 EXTERNAL AIRPLANE LIBRARY. COMFAA allows for an external airplane library where characteristics of the airplane can be changed and additional airplanes added as desired. Functions are provided for modifying the characteristics of an airplane and saving the modified airplane in the external library. There are no safeguards in the COMFAA program to assure that airplane parameters in the external library are feasible or appropriate. The user is responsible to assure that all data is correct.

When saving an airplane from the internal library to the external library, the COMFAA program will calculate the tire contact area based upon the gross load, maximum aft center of gravity, and tire pressure. This value is recorded in the external library and is used for calculating the pass-to-coverage (P/C) ratio in the pavement thickness mode. Since the tire contact area is constant, the P/C ratio is also constant in the pavement thickness mode. This fixed P/C ratio should be used for converting passes to coverages for pavement thickness determination and equivalent airplane operations.

3.5 USING THE COMFAA PROGRAM. Using the COMFAA program to calculate ACN values is visually interactive and intuitive. The user selects the desired airplane, confirms the physical properties of the airplane, and clicks on the ACN flexible or ACN Rigid button to determine the ACN for the four standard subgrade conditions. A help file is included with the program to assist the user should difficulties occur. Operation of the COMFAA program is highlighted in Figures 3-1 and 3-2.

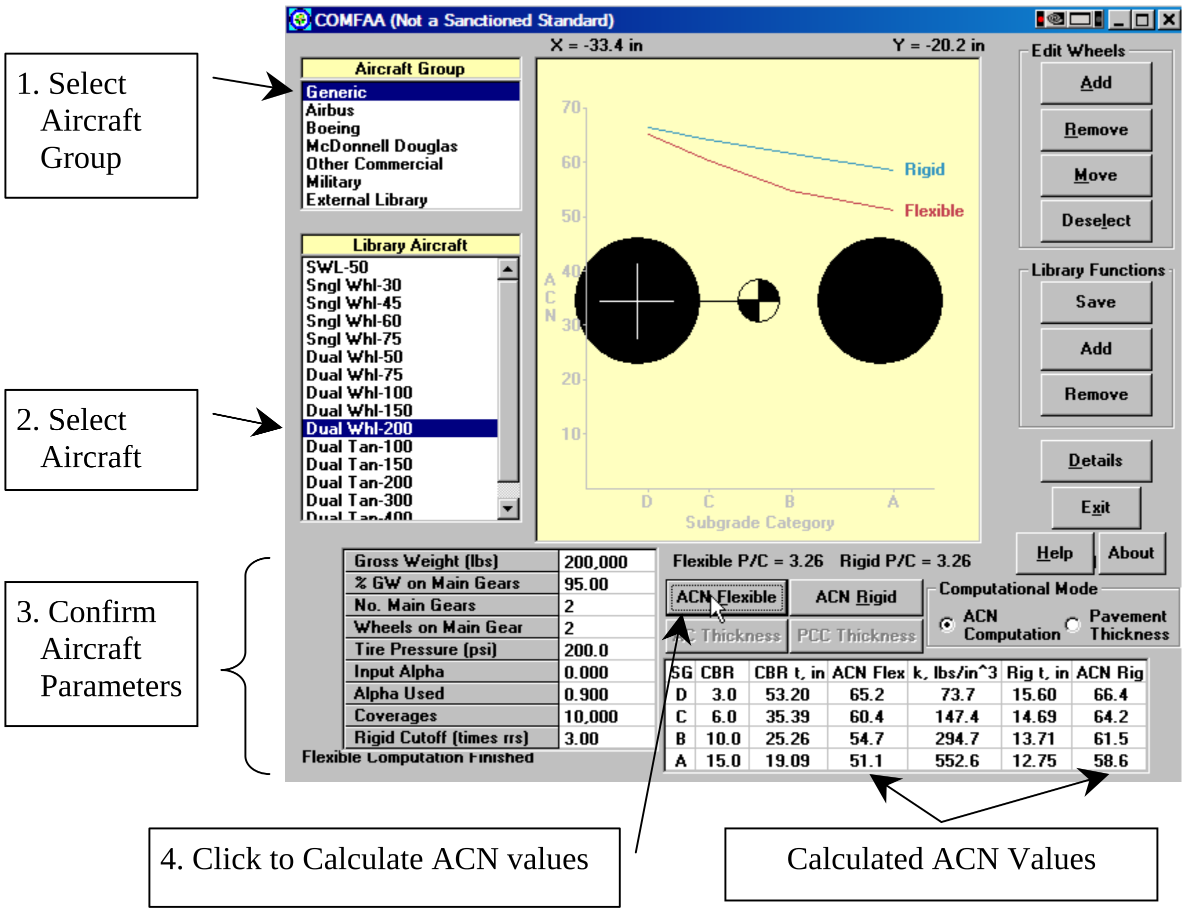

FIGURE 3-1. Operation of the COMFAA Program in ACN Mode

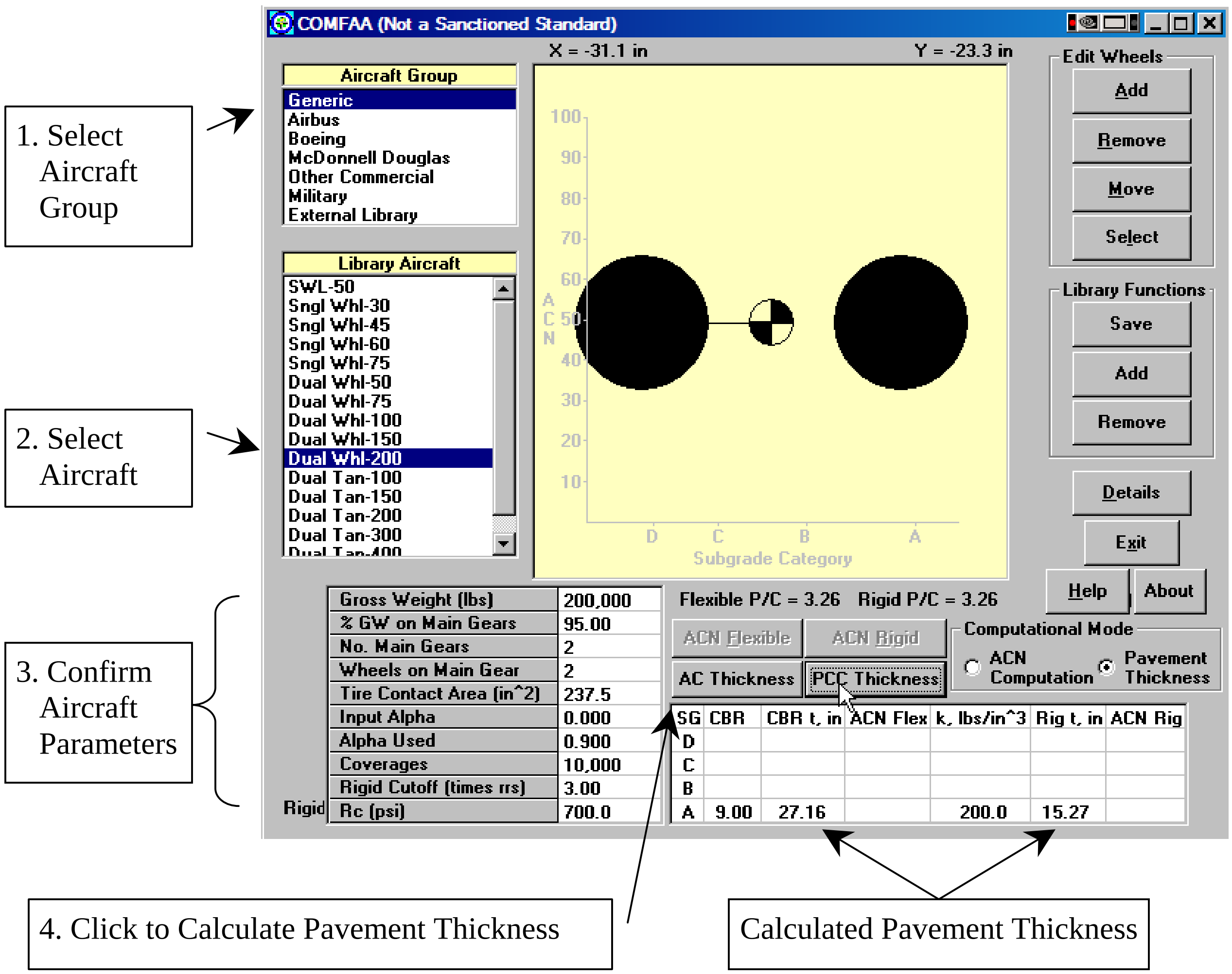

FIGURE 3-2. Operation of the COMFAA Program in Pavement Thickness Mode

CHAPTER 4. DETERMINATION OF PCN NUMERICAL VALUE.

4.0 PCN CONCEPT. In fundamental terms, the determination of a pavement rating in terms of PCN is a process of determining the ACN for the selected critical or most demanding airplane and reporting the ACN value as the PCN for the pavement structure. Under these conditions any airplane with an ACN equal to or less than the reported PCN value can safely operate on the pavement subject to any limitations on tire pressure.

4.1 DETERMINATION OF THE NUMERICAL PCN VALUE. Determination of the numerical PCN value for a particular pavement can be based upon one of two procedures. The procedures are known as the "Using" airplane method and the "Technical" evaluation method. ICAO procedures permit member states to determine how PCN values will be determined based upon internally developed pavement evaluation procedures. Either procedure may be used to determine a PCN but the methodology must be reported as part of the posted rating.

4.2 USING AIRPLANE METHOD TO DETERMINE PCN. The using airplane method is a simple procedure where ACN values for all airplanes currently permitted to use the pavement facility are determined and the largest ACN value reported as the PCN. This method is easy to apply and does not require detailed knowledge of the pavement structure.

a. Assumptions of the Using Airplane Method. An underlying assumption with the using airplane method is that the pavement structure has the structural capacity to accommodate all airplanes in the traffic mixture and that each airplane is capable of operating on the pavement structure without restriction.

b. Inaccuracies of the Using Airplane Method. The accuracy of this method is greatly improved when airplane traffic information is available. Significant over estimation of the pavement capacity can result if an excessively damaging airplane which uses the pavement on a very infrequent basis is used to determine the PCN. Likewise, significant under estimation of the pavement capacity can lead to uneconomic utilization of the pavement in that acceptable traffic may be prevented from operating. Although there are no minimum limits on frequency of operation before an airplane is considered as part of the normal traffic, the reporting agency must use a rational approach to avoid overstating or understating the pavement capacity. Use of the using airplane method is discouraged on a long term basis due to the concerns listed above.

4.3 Technical Evaluation Method to Determine PCN. The strength of a pavement section is difficult to summarize in a precise manner and will vary depending upon the unique combination of airplane loading conditions, frequency of operation, and pavement support conditions. The technical evaluation method attempts to address these and other site specific variables to determine reasonable pavement strength. In general terms, for a given pavement structure and given airplane, the allowable number of operations (traffic) will decrease as the intensity of pavement loading increases (increase in airplane weight). It is entirely possible that two pavement structures with different cross sections will report similar strength. However, the permissible airplane operations will be considerably different. This discrepancy must be acknowledged by the airport operator and may require operational limitations administered outside of the ACN-PCN system. All of the factors involved in determining a pavement rating are important and it is for this reason that pavement ratings should not be viewed in absolute terms, but rather as estimations of a representative value. A successful pavement evaluation is one that assigns a pavement strength rating which considers the effects of all variables on the pavement.

The accuracy of a technical evaluation is better than the using airplane procedure but requires a considerable increase in time and resources. Pavement evaluation may require a combination of on-site inspections, load bearing tests and engineering judgment. It is common to think of pavement strength rating in terms of ultimate strength or immediate failure criteria. However, pavements are rarely removed from service due to instantaneous structural failure. A decrease in the serviceability of a pavement is commonly attributed to increases in surface roughness or localized distress such as rutting or cracking. Determination of the adequacy of a pavement structure must not only consider the magnitude of pavement loads but the impact of the accumulated effect of traffic volume over the intended life of the pavement.

a. Determination of the PCN Value. The PCN numerical value is determined from an allowable load rating. While it is important not to confuse the PCN value with a pavement design parameter, the PCN is developed in a similar fashion. An allowable load rating is determined by applying the same principles as those used for pavement design. In determining the allowable load rating, factors such as frequency of operations and permissible stress levels are taken into account. Allowable load ratings are often stated in terms of airplane gear type and maximum gross airplane weight as these variables are used in the pavement design procedure. Missing from the stated load rating but just as important is frequency of operation. In determining an allowable load rating the evaluation must address whether the allowable load rating represents the pavement strength over a reasonable frequency of operation. Once the allowable load rating is established, the determination of the PCN value is a simple process of determining the ACN of the airplane representing the allowable load and reporting the value as the PCN.

b. Concept of Equivalent Traffic. The ACN-PCN method is based upon design procedures which establish one airplane as the critical or most demanding on the pavement structure. Calculations necessary to determine the PCN can only be performed for one airplane at a time. The ACN-PCN method does not directly address how to represent a traffic mixture as a single airplane. To address this limitation, the FAA uses the equivalent airplane concept to consolidate entire traffic mixtures into one representative airplane. The procedures for establishing an equivalent airplane from a traffic mixture are provided in Appendix A1.

c. Counting Airplane Operations. When evaluating or designing a pavement section it is important to account for the number of times the pavement will be stressed. As discussed in paragraph 2.2, an airplane may have to pass over a given section of pavement numerous times before the portion of pavement considered for evaluation receives one full stress application. While statistical procedures exist to determine the passes required for one full stress application, the evaluation of a pavement section for PCN determination must also consider how airplanes use the pavement in question. A conservative approach is used in pavement design procedures where it is assumed that each airplane using the airport must land and take off once per cycle. Since the arrival or landing weight of the airplane is almost always less than the departure weight, the design procedure only counts one pass at the departure weight for analysis. These departures are usually discussed in term of departures per year or annual departures. A detailed discussion of traffic analysis is provided in Appendix A1.

4.4 LIMITATIONS OF THE PCN. The PCN value is for reporting relative pavement strength only and should not be used for pavement design or as a substitute for evaluation. Pavement design and evaluation are complex engineering problems which require detailed analyses. They cannot be reduced to a single number. The PCN rating system uses a continuous scale to compare pavement strength where higher values represent pavements with larger load capacity.

4.5 REPORTING THE PCN. The PCN system uses a coded format to maximize the amount of information contained in a minimum number of characters and to facilitate computerization. The PCN for a pavement is reported as a 5 part number where the following codes are ordered and separated by forward slashes.

- Numerical PCN Value
- Pavement type,
- Subgrade category,
- Allowable tire pressure, and
- Method used to determine the PCN.

a. Numerical PCN Value. The PCN numerical value is a relative indication of the load carrying capacity of a pavement in terms of a standard single wheel load at a tire pressure of 181 psi (1.25 MPa). The PCN value may be reported to the nearest 1/10th of a whole number; however, it is impractical to expect this degree of accuracy. The PCN value should be reported in whole numbers, rounding off any fractional parts to the nearest whole number. For pavements of diverse strengths, the controlling PCN numerical value for the weakest segment of the pavement should be reported as the strength of the pavement. Engineering judgment may be required here in that if the weakest segment is not in the most heavily used part of the runway, then another representative segment may be more appropriate as the determinate PCN.

b. Pavement Type. For the purpose of reporting PCN values, pavement types are considered to function as either Flexible or Rigid structures. Table 4-1 lists the pavement codes for the purposes of reporting PCN.

Table 4-1. Pavement Codes for Reporting PCN

Pavement Type	Pavement Code
Flexible	F
Rigid	R

i) Flexible Pavement. Flexible pavements support loads through bearing rather than flexural action. They comprise several layers of selected materials designed to gradually distribute loads from the surface to the layers beneath. The design ensures that load transmitted to each successive layer does not exceed the layer’s load-bearing capacity.

ii) Rigid Pavement. Rigid pavements employ a single structural layer, which is very stiff or rigid in nature, to support the pavement loads. The rigidity of the structural layer and resulting beam action enable rigid pavement to distribute loads over a large area of the subgrade. The load carrying capacity of a rigid structure is highly dependent upon the strength of the structural layer which relies on uniform support from the layers beneath.

iii) Composite Pavement. Various combinations of pavement types and stabilized layers can result in complex pavements which could be classified as between rigid or flexible. A pavement section may be comprised of multiple structural elements representative of both rigid and flexible pavements. Composite pavements are most often the result of pavement surface overlays applied at various stages in the life of the pavement structure. If a pavement is of composite construction, the pavement type should be reported as the type that most accurately reflects the structural behavior of the pavement. The method used in computing the PCN is the best guide in determining how to report the pavement type. For example, if a runway is composed of a rigid pavement with a bituminous overlay, the usual manner of determining the load carrying capacity is to convert the pavement to an equivalent thickness of rigid pavement. In this instance the pavement type should be reported as a rigid structure. A general guideline is that when the bituminous overlay reaches 75 to 100% of the rigid pavement thickness the pavement can be considered as a flexible pavement. It is permissible to include a note stating that the pavement is of composite construction but only the rating type, “R” or “F”, is utilized in the assessment of the pavement load capacity.

c. Subgrade Strength Category. As discussed in Paragraph 2-1, there are 4 standard subgrade strengths identified for calculating and reporting ACN or PCN values. The values for rigid and flexible pavements are reported in Tables 2-1 and 2-2.

d. Allowable Tire Pressure. Table 4-2 lists the allowable tire pressure categories identified by the ACN-PCN system. The tire pressure codes apply equally to rigid or flexible pavement section, however the application of the allowable tire pressure differs substantially for rigid and flexible pavements.

TABLE 4-2. Tire Pressure Codes For Reporting PCN

Category	Code	Tire Pressure Range
High	W	No pressure limit
Medium	X	Pressure limited to 218 psi (1.5 MPa)
Low	Y	Pressure limited to 145 psi (1.00 MPa)
Very Low	Z	Pressure limited to 73 psi (0.50 MPa)

i) Tire Pressures on Rigid Pavements. Airplane tire pressure will have little effect on pavements with Portland cement concrete surfaces. Rigid pavements are inherently strong enough to resist tire pressures higher than currently used by commercial airplanes and can usually be rated as code W.

ii) Tire Pressures on Flexible Pavements. Tire Pressures may be restricted on asphaltic concrete depending upon the quality of the asphalt mixture and climatic conditions. Tire pressure effects on an asphalt layer relate to the stability of the mix in resisting shearing or densification. A poorly constructed asphalt pavement can be subject to rutting due to consolidation under load. The principal concern in resisting tire pressure effects is with stability or shear resistance of lower quality mixtures. A properly prepared and placed mixture which conforms to FAA specification Item P-401, can withstand substantial tire pressure in excess of 218 psi. Improperly prepared and placed mixtures can show distress under tire pressures of 100 psi or less. Although these effects are independent of the asphalt layer thickness, pavements with well-placed asphalt of 4 to 5 inches in thickness can generally be rated with code X or W, while thinner pavement of poorer quality asphalt should not be rated above code Y.

e. Method Used to Determine PCN. Two pavement evaluation methods are recognized in the PCN system. If the evaluation represents the results of a technical study, the evaluation method should be coded “T”. If the evaluation is based on “using airplane” experience, the evaluation method should be coded “U”. Technical evaluation implies that some form of technical study and computation were Involved in the determination of the PCN. Using airplane evaluation means the PCN was determined by selecting the highest ACN among the airplanes currently using the facility and not causing pavement distress. PCN values computed from allowable gear loads as shown in the FAA 5010, Airport Master Record, should be considered as technical evaluations. Publication of a “using airplane” evaluation in the FAA 5010 database is permitted only by mutual agreement between the airport owner and the FAA.

f. Example PCN Reporting. An example of a PCN code is 80/R/B/W/T--with 80 expressing the PCN numerical value, R is for rigid pavement, B for medium strength subgrade, W for high allowable tire pressure, and the T indicates the PCN value was obtained by a technical evaluation.

g. Report PCN values to the FAA. Once a PCN value and the coded entries are determined, the PCN code should be reported to the regional Federal Aviation Administration (FAA) Airports Division, either in writing or as part of the annual FAA updating of the Airport Master Record, FAA Form 5010-l. The PCN code is then forwarded to FAA headquarters and disseminated by the National Flight Data Center through aeronautical publications such as the Airport/Facility Directory and the Aeronautical Information Publication. An airplane's ACN can then be compared with the published PCN to determine if the airplane can safely operate on the airport’s runways subject to any limitation on tire pressure.

APPENDIX 1. EQUIVALENT TRAFFIC

1.0 Equivalent Traffic. A detailed method, based on the procedures originally introduced in AC 150/5320-6C (outdated version) is presented to allow the calculation of the combined effect of multiple airplanes in the traffic mix for an airport. This combined traffic is brought together into the equivalent traffic of a critical airplane. This is necessary in that the procedure used to calculate ACN allows only one airplane at a time. By combining all of the airplanes in the traffic mix into an equivalent critical airplane, calculation of a PCN that includes the effects of all traffic becomes possible. It is recognized that there are other methods of determining equivalent traffic. However, the method described herein has been developed and utilized over a period of years by the FAA.

The assessment of equivalent traffic, as described in this section, is needed only in the process of determining PCN using the Technical method, and may be disregarded when the "using airplane" method is employed.

In order to arrive at a technically derived PCN, it is necessary to determine the maximum allowable or commonly sustained gross weight of the critical airplane (i.e. the allowable weight on a given landing gear configuration). This in turn requires that the pavement design and airplane loading characteristics be examined in detail. Consequently, the information presented in this appendix appears at first to apply to pavement design rather than a PCN determination. However, with this knowledge in hand, an engineer will be able to arrive at a PCN that will have a solid technical foundation.

1.1 Equivalent Traffic Terminology. In order to determine a PCN, as based on the technical evaluation method, it is necessary to define common terms used in airplane traffic and pavement loading. The terms arrival, departure, pass, coverage, load repetition, operation, and traffic cycle are often used interchangeably by different organizations when determining the effect of airplane traffic operating on a runway. It is not only important to determine which of the airplane movements need be counted when considering pavement stress, but how these terms apply in relation to the pavement design and evaluation process. In general, and for the purposes of this document, they are differentiated as follows:

a. Arrival (Landing) and Departure (Takeoff). Typically, airplanes arrive at an airport with a lower amount of fuel than is used at takeoff. As a consequence, the stress loading of the wheels on the runway pavement is less when landing than at takeoff due to the lower weight. This is true even at the touchdown impact, in that there is still lift on the wings, which alleviates the dynamic vertical force. Because of this, the FAA pavement design procedure only considers departures and ignores the arrival traffic count. However, if the airplanes do not receive additional fuel at the airport, then the landing weight will be substantially the same as the takeoff weight (discounting the changes in passenger count and cargo), and the landing operation should be counted the same as a takeoff for pavement stress loading cycles. In this latter scenario there are two equal load stresses on the pavement for each traffic count (departure), rather than just one. Regardless of the method of counting load stresses, a traffic cycle is defined as one takeoff and one landing of the same airplane, subject to a further refinement of the definition in the following text.

b. Pass. A pass is a one time transaction of the airplane over the runway pavement. It could be an arrival, a departure, a taxi operation, or all three, depending on the loading magnitude and the location of the taxiways. Figure A1-1 shows typical traffic patterns for runways having either parallel taxiways or central taxiways. A parallel taxiway requires that none or very little of the runway be used as part of the taxi movement. A central taxiway requires that a large portion of the runway be used during the taxi movement.

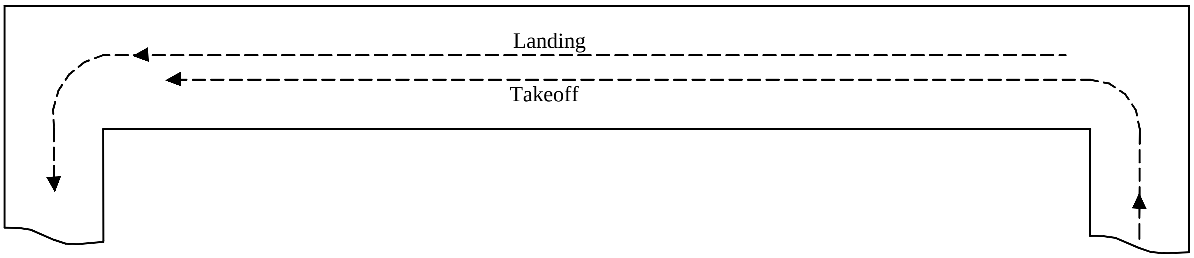

Figure A1-1a. Runway with Parallel Taxiway

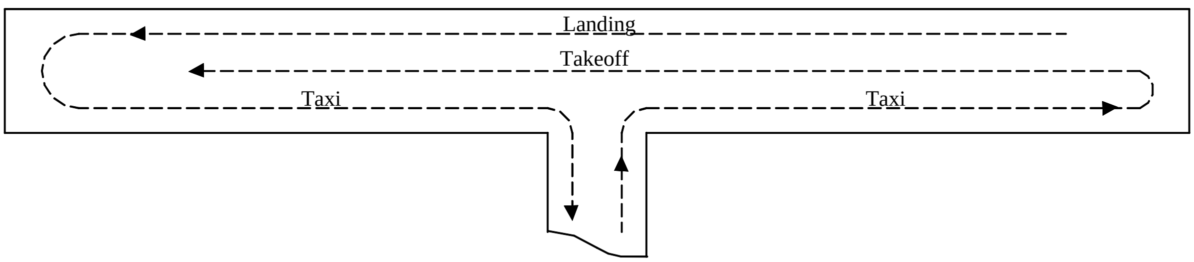

Figure A1-1b. Runway with Central Taxiway

Figure A1-1. Traffic Load Distribution Patterns

i. Parallel Taxiway Scenario. In the case of the parallel taxiway, as shown in Figure A1-1a, there are two possible loading situations that can occur. Both of these situations assume that the passenger count and cargo payload are approximately the same for the entire landing and takeoff cycle:

1. If the airplane obtains fuel at the airport, then a traffic cycle consists of only one pass, since the landing stress loading is considered at a reduced level, which is a fractional equivalence. For this condition only the takeoff pass is counted, and the ratio of passes to traffic cycles (P/TC) is 1.

2. If the airplane does not obtain fuel at the airport, then both landing and takeoff passes should be counted, and a traffic cycle consists of two passes of equal load stress. In this case, the P/TC ratio is 2.

ii. Central Taxiway Scenario. In the case of the central taxiway, as shown in Figure A1-1b, there also are two possible loading situations that can occur. In a similar manner as was done for the parallel taxiway condition, both of these situations assume that the payload is approximately the same for the entire landing and takeoff cycle:

1. If the airplane obtains fuel at the airport, then both the takeoff and taxi to takeoff passes should be counted since they result in a traffic cycle consisting of two passes at the maximum load stress. The landing pass can be ignored in this case. It is recognized that only part of the runway is used during some of these operations, but it is conservative to assume that the entire runway is covered each time a pass occurs. For this situation, the P/TC ratio is 2.

2. If the airplane does not obtain fuel at the airport, then both the landing and takeoff passes should be counted, along with the taxi pass, and a traffic cycle consists of three passes at loads of equal magnitude. In this case, the P/TC ratio is 3.

Notwithstanding the previous discussion on the magnitude of the P/TC ratio for the different runway and taxiway conditions, an alternate procedure would be to consider the P/TC ratio to be 1 for all situations. Since landing and takeoff only apply full load to perhaps the end 1/3 of the runway (opposite ends for no shift in wind direction), a less conservative approach would be to count one pass for both landing and takeoff. However, it is recommended to conduct airport evaluations on the conservative side, which is to consider that the entire runway has been covered during any one of the passes.

c. **Coverage.** When an airplane traverses on a runway, it seldom travels in a perfectly straight line or over the exact same wheel path as before. It will wander on the runway with a statistically normal distribution. One coverage occurs when a unit area of the runway has been traversed by a wheel of the airplane main gear. Due to the random wander, this unit area may not be covered by the wheel every time the airplane is on the runway. The number of passes required to statistically cover the unit area one time on the pavement is related by the pass to coverage (P/C).

Although the terms coverage and P/C ratio have commonly been applied to both flexible and rigid pavements, the P/C ratio has a slightly different meaning when applied to flexible and rigid pavements. This is due to the manner in which flexible and rigid pavements are considered to react to various types of gear configurations. For gear configurations with wheels in tandem, such as dual tandem (2D) and triple dual tandem (3D), the ratios are different for flexible and rigid pavements, and using the same term for both types of pavements may become confusing. It is incumbent upon the user to select the proper value for flexible and rigid pavements.

While coverages are used by the COMFAA program only passes can be determined (counted) by observation. The P/C ratio is necessary to convert passes to coverages for use in the program. The P/C ratio for any airplane can be determined from the COMFAA program. This ratio is different for each airplane due to the different number of wheels, main gear configurations, tire contact areas, and load on the gear. Although the ratio will change slightly for each airplane when the tire contact area varies due to changes in applied load, for the purposes of this document the P/C ratio will be reported as the ratio obtained from the COMFAA program in pavement thickness mode which is based upon manufacturer's recommended tire deflection at 95% of the gross load on the main landing gear(s).

The P/C ratios for gears with wheels in tandem are different for flexible and rigid pavement. This difference occurs due to the method in which the flexible and rigid pavements are assumed to handle stress. It is considered that the flexible pavement loading pattern has a series of stress peaks, depending on the number of wheels in tandem, while a rigid pavement acts as a single deflecting plate, with only one stress peak per group of wheels. Generally, a single or dual gear arrangement will provide only one load stress per pass, regardless of the pavement type, in that there is only one set of wheels traversing a given place on the pavement. However, a dual tandem gear stresses a flexible pavement twice in that there are two repetitions of the load on flexible pavement, and it stresses a rigid pavement once due to the effect of only one stress loading per group of wheels. Likewise, a triple dual tandem gear stresses the flexible pavement three times to one time for rigid pavement. Gear configurations with tandem spacing exceeding 72 inches are treated as individual load peaks for flexible and rigid pavements in the COMFAA program.

d. Operation. The meaning of this term is unclear when used in pavement design or evaluation. It could mean a departure at full load or a landing at minimal load. It is often used interchangeably with pass or traffic cycle. When this description of an airplane activity is used, additional information should be supplied. It is usually preferable to use the more precise terms described in this section.

e. Traffic Cycle and Traffic Cycle Ratio. As has been discussed, a traffic cycle can include a landing pass, a takeoff pass, a taxi pass or all three. For pavement design or evaluation, the ratio of traffic cycles to coverages in flexible pavement, rather than passes to coverages, is required since there could be one or more passes per traffic cycle. When only one pass on the operating surface is assumed for each traffic count, then the P/C ratio is sufficient. However, when situations are encountered where more than one pass is considered to occur during the landing to takeoff cycle, then the TC/C ratio is necessary in order to properly account for the effects of all of the traffic. These situations occur most often when there are central taxiways or fuel is not obtained at the airport.

Equation A1-1 translates the P/C ratio to the TC/C ratio for flexible and rigid pavements by including the previously described ratio of passes to traffic cycles (P/TC):

$$TC/C = P/C \div P/TC \qquad \text{(A1-1)}$$

Where:

TC = Traffic Cycles
C = Coverages
P = Passes

Determination of the TC/C ratio can best be illustrated by examples. Table A1-1 shows typical ratios for flexible pavement runways for situations in which fuel is not obtained at the airport. Typical values of the P/C ratio are shown in this table, but different ratios can be substituted for other airplanes. Refer to Figure A1-1 for guidance in determining the number of passes utilized for each traffic count. Note that the number of traffic cycles to complete one coverage is reduced considerably for a runway with a central taxiway, as opposed to one with a parallel taxiway. The effect of this is that a runway with a central taxiway will experience more load stresses for each traffic count than one with a parallel taxiway.

Table A1-1. TC/C Ratio for Flexible Pavements - Additional Fuel Not Obtained

Taxiway Type	Typical Dual Gear (D)	Typical Dual Tandem Gear (2D)	Typical Triple Dual Tandem Gear (3D)
P/C	3.6	1.8	1.4
P/TC - Parallel	2	2	2
P/TC - Central	3	3	3
TC/C - Parallel	1.8	0.9	0.7
TC/C - Central	1.2	0.6	0.5

Table A1-2 shows the same information for a situation in which additional fuel is obtained at the airport. From a comparison of theses two tables, it can be seen that for a runway having a central taxiway and where fuel is not obtained at the airport, there are more traffic cycles than for a runway in which a parallel taxiway exists and fuel is obtained at the airport. For example, the typical dual gear TC/C for a central taxiway in Table A1-1 is 1.2 compared with that of 3.6 for the parallel taxiway in Table A1-2, resulting in three times the number of passes for each traffic count. Additionally, as the number of wheels increases, the TC/C ratio decreases, regardless of the taxiway configuration. The effect of this is that there are more loading cycles in terms of coverages per traffic count on flexible pavement with the increased number of wheels.

Table A1-2. TC/C Ratio for Flexible Pavements - Additional Fuel Obtained

Taxiway Type	Typical Dual Gear (D)	Typical Dual Tandem Gear (2D)	Typical Triple Dual Tandem Gear (3D)
P/C	3.6	1.8	1.4
P/TC - Parallel	1	1	1
P/TC - Central	1	1	1
TC/C - Parallel	3.6	1.8	1.4
TC/C - Central	1.8	0.9	0.7

Table A1-3 shows typical ratios for rigid pavements for situations in which fuel is not obtained at the airport, while Table A1-4 shows the same information for cases in which additional fuel is obtained at the airport. The same comparison as above is seen in which a different number of traffic cycles occur between the runways with differing taxiway configurations. However, unlike the flexible pavement example, the ratio of traffic cycles to load stress is not very sensitive to gear configuration. For example, from Tables A1-3 and A1-4, both the dual and dual-tandem gears have the same TC/C ratio, while the triple dual tandem gear is only slightly different. The effect of this is that for the same taxiway type and fuel loading situation, the level of load repetitions per traffic cycle on rigid pavement is virtually the same, regardless of the gear configuration.

Table A1-3. TC/C Ratio for Rigid Pavements - Additional Fuel Not Obtained

Taxiway Type	Typical Dual Gear (D)	Typical Dual Tandem Gear (2D)	Typical Triple Dual Tandem Gear (3D)
P/C	3.6	3.6	4.2
P/TC - Parallel	2	2	2
P/TC - Central	3	3	3
TC/C - Parallel	1.8	1.8	2.1
TC/C - Central	1.2	1.2	1.3

Table A1-4. TC/LR Ratio for Rigid Pavements - Additional Fuel Obtained

Taxiway Type	Typical Dual Gear (D)	Typical Dual Tandem Gear (2D)	Typical Triple Dual Tandem Gear (3D)
P/C	3.6	3.6	4.2
P/TC - Parallel	1	1	1
P/TC - Central	2	2	2
TC/C - Parallel	3.6	3.6	4.2
TC/C - Central	1.8	1.8	2.1

1.2 Equivalent Traffic Based on Gear Type. In order to complete the equivalent traffic calculation, all other significant airplanes in the traffic mix must be first converted to a critical airplane in terms of gear type and traffic cycles in that this other traffic also must be accounted for in the overall pavement design life. Secondly, the converted gear types must be in turn converted to a critical airplane equivalent in terms of load magnitude. An airplane, which is regularly using the pavement that has the greatest thickness requirements, based on its individual operational characteristics, is defined as the critical airplane.

Table A1-5 provides conversion factors for common gear configurations which are used to convert a given gear type to that of the critical airplane. After this conversion, each airplane in the traffic mix, and its corresponding traffic cycles, will be represented by the same gear configuration as the critical airplane.

Table A1-5. Conversion Factors to Convert From One Landing Gear Type to Another

To Convert From Gear type (N)	To gear type (M)	Multiply Traffic Cycles By
S	D	0.80
S	2D	0.51
S	3D	0.33
D	S	1.25
D	2D	0.64
D	3D	0.41
2D	S	1.95
2D	D	1.56
2D	3D	0.64
3D	S	3.05
3D	D	2.44
3D	2D	1.56
2D/2D2	D	1.56
2D/2D2	2D	1.00

The general equation for this conversion is:

$$0.8^{(M-N)} \qquad \text{(A1-2)}$$

Where:

M = the number of wheels on the critical airplane main gear.

N = the number of wheels on the converted airplane gear.

As an example of the use of gear configuration conversion factors Table A1-6 shows the gear equivalencies for a dual tandem (2D) gear in a sample traffic mix, while Table A1-7 shows the same gear equivalencies for a dual gear (D). The equivalent traffic cycles totals are shown for comparison purposes only, and are not necessary for critical airplane calculations. It can be seen from a comparison of these totals that the selection of the critical airplane is very important for the overall evaluation process in that an incorrect selection leads to an erroneous number of equivalent traffic cycles. This is evident in Table A1-6 where the overall total of annual traffic cycles is 15,200 compared with the total equivalent dual tandem traffic cycles of 12,632, whereas in Table A1-7, the total equivalent dual traffic cycles is 19,720.

Table A1-6. Equivalency Conversion to a Dual Tandem (2D) Gear Type

Airplane	Gear Type	Annual Traffic Cycles (TC)	Conversion Factor	Equivalent (2D) TC
727-200	D	400	0.64	256
737-300	D	6,000	0.64	3840
A319-100	D	1,200	0.64	768
747-400	2D/2D2	3,000	1.0	3,000
767-200ER	2D	2,000	1.0	2,000
DC8-63	2D	800	1.0	800
MD11	2D	1,500	1.0	1,500
777-200	3D	300	1.56	468
		15,200		12,632

TableA1-7. Equivalency Conversion to a Dual Gear Type

Airplane	Gear Type	Annual Traffic Cycles	Conversion Factor	Equivalent (D) TC
727-200	D	400	1.0	400
737-300	D	6,000	1.0	6,000
A319-100	D	1,200	1.0	1,200
747-400	2D/2D2	3,000	1.56	4,680
767-200ER	2D	2,000	1.56	3,120
DC8-63	2D	800	1.56	1,248
MD11	2D	1,500	1.56	2,340
777-200	3D	300	2.44	732
		15,200		19,720

1.3 Equivalent Traffic Based on Load Magnitude. After the airplanes have been grouped into the same gear configuration, it is necessary to determine the total equivalent traffic cycles of each airplane in terms of the critical airplane as based on the relative load magnitude. As was stated for the gear type conversion procedure, this step also requires that the critical airplane be previously selected.

When computing equivalent traffic cycles of the critical airplane based on load magnitude, there are several simplifying rules that can be utilized:

- For the purposes of equivalent traffic cycle calculations, it is generally sufficient to use single wheel loads based on 95% of gross airplane weight on the main gear.

- Since it is difficult to determine current or projected operational weights, maximum taxi gross weights of each airplane may be used for this calculation, except as noted next.

- Widebody airplanes are all treated as 300,000-pound dual-tandem gear airplane (35,625-pound single wheel load), even when the critical airplane is a widebody, for this calculation. Airplanes with dual tandem gear geometries where the dual spacing exceeds 30 inches (0.76 m) and tandem spacing exceeds 55 inches (1.40 m) are treated as widebody airplanes. Note that this procedure is followed only for determining traffic equivalencies, and it should not be used for pavement design or evaluation.

After the procedure in paragraph A1.2 to convert gear types for the airplanes of the traffic mix to that of the critical airplane is completed, the traffic cycles of each airplane must be converted to equivalent traffic cycles of the critical airplane. This conversion addresses the effect of wheel load magnitude may be calculated by applying Equation A1-3:

$$\mathrm{Log\,R_1} = \mathrm{Log\,R_2} \times \sqrt{\frac{\mathrm{W_2}}{\mathrm{W_1}}} \qquad \text{or} \qquad R_1 = (R_2)^{\sqrt{W_2/W_1}} \tag{A1-3}$$

Where:

R_1 = Equivalent traffic cycles of the critical airplane
R_2 = Traffic cycles of a given airplane expressed in terms of the critical airplane landing gear
W_1 = Wheel load of the critical airplane
W_2 = Wheel load of the airplane in question

Table A1-8 shows how the above calculations are combined to determine the equivalent traffic cycles of the critical airplane. For this example, assume that the 747-400 is the critical airplane. It can be seen that the original 3,000 annual traffic cycles of the 747-400 have increased to an equivalent 11,410 due to the combined effect of the other airplanes in the traffic mix. The R_2 column is from Table A1-6.

Table A1-8. Equivalent Traffic Cycles Based on Load Magnitude

Airplane	Operating Weight lb	(W_2) Single Wheel Load, lb	(R_2) (2D) TC	$(A)^{1/2}$ Wheel Load Ratio	(R_1) Equivalent 747-400 TC	
727-200	185,000	43,940	256	1.111	473	
737-300	130,000	30,875	3,840	0.931	2,172	
A319-100	145,000	34,440	768	0.983	687	
747-400	820,000	35,625 (W_1)	3,000	1.000	3000	(Critical Airplane)
767-200ER	370,000	35,625	2,000	1.000	2,000	
DC8-63	330,000	39,190	800	1.049	1,109	
A300-B4	370,000	35,625	1,500	1.000	1,500	
777-200	600,000	35,625	468	1.000	469	
			12,632		11,410	

Note that a sensitive factor in this table is the single wheel load and its ratio to the critical airplane single wheel load. Any changes in the single wheel load magnitude are reflected in the wheel load ratio, which is used as an exponent in the calculation of equivalent traffic cycles. For example, the 727-200 equivalent traffic is shown to increase from 256 to 473, even though this is a relatively small airplane as compared to the 747-400. Alternately, the 737-300 equivalent traffic has reduced from 3,840 to 2,172 due to the relative magnitude of the single wheel loads.

APPENDIX 2. PCN DETERMINATION EXAMPLES

1.0 The Using Airplane Method. The *Using* airplane method of determining PCN is presented in the following steps. This procedure can be used when there is limited knowledge of the existing traffic and runway characteristics. It is also useful when engineering analysis is neither possible nor desired. Airport authorities should be more flexible in the application of a *Using* airplane PCN in that the rating has not been rigorously determined.

There are two basic steps required to arrive at a *Using* airplane PCN:

1. Determine the airplane with the highest ACN in the traffic mix currently using the runway. This is the critical airplane.

2. Assign the ACN of the critical airplane as the PCN.

The following list is an expansion of the basic steps that are necessary for determining a PCN as based on the *Using* airplane method:

1. Assign the pavement surface type as Code *F* or *R*.

2. From available records, determine the average strength of the pavement subgrade. If the subgrade strength is not known, make a judgment of High, Medium, Low or Ultra Low.

3. Determine which airplane has the highest ACN from a list of airplanes that are presently using the runway, based on the surface code from Step 1 and the subgrade code from Step 2. ACN values may be determined from the COMFAA program or from ACN graphs as found in the manufacturer's published *Airplane Characteristics for Airport Planning* manuals. Use the same subgrade code for each of the airplanes when determining the maximum ACN. Base ACNs on the highest operating weight of the airplanes at the airport if the data is available; otherwise use an estimate or the published maximum allowable gross weight of the airplane in question. The airplane with the highest ACN, and which regularly uses the pavement, is the critical airplane.

4. The PCN is simply the ACN of the critical airplane, with appropriate tire pressure and evaluation codes added. The numerical value of the PCN may be adjusted up or down at the preference of the airport authority. Reasons for adjustment include local restrictions, allowances for certain airplanes, or pavement conditions.

5. The tire pressure code (W, X, Y, or Z) should represent the highest tire pressure of the airplane fleet currently using the runway. For flexible pavements, Code *X* should be used if no higher tire pressure is evident from among the existing traffic. It is commonly understood that concrete can tolerate substantially higher tire pressures, and the rigid pavement rating should normally be assigned as *W*.

6. The evaluation method for the *Using* airplane method is reported as *U*.

1.2 Using Airplane Example for Flexible Pavements. The following example illustrates the *Using* airplane PCN process for flexible pavements:

An airport has a flexible (asphalt-surfaced) pavement runway with a subgrade strength of CBR 9 and traffic having the operating gross weights and ACNs shown in Table A2-1.

Table A2-1. *Using* Airplane and Traffic for a Flexible Pavement

Airplane	Operating Weight, lbs	Tire Pressure (psi)	% GW Main Gear For ACN	ACN F/B	Annual Departures
B727-200	185,000	148	96.00	48	400
B737-300	130,000	195	90.86	32	6,000
A319-100	145,000	196	92.60	34	1,200
B747-400	820,000	200	93.32	59	3,000
B767-300ER	370,000	190	92.40	50	2,000
DC8-63	330,000	194	96.12	53	800
A300-B4	370,000	205	94.00	57	1,500
B777-200	600,000	215	95.42	52	300

- Since this is a flexible pavement, the pavement type code is *F*, (Table 2-1).
- The subgrade strength under the pavement is CBR 9, which is *Medium, Code B* category. (Table 2-2)
- The highest tire pressure of any airplane in the traffic mix is 215 psi, which is in the *X* category (Table 4-2).
- From the above list, the critical airplane is the B747-400, since it has the highest ACN of the group at the operational weights shown (59/F/B). Additionally, it has regular service as compared to the rest of the traffic, which qualifies it as a possible critical airplane.
- Since there was no engineering analysis done in this example, and the rating was determined simply by examination of the current airplanes using the runway, the evaluation code from Table 2-5 is *U*.
- Based on the results of the previous steps, the pavement should tentatively be rated as PCN 59/F/B/X/U, assuming that the pavement is performing satisfactorily under the current traffic.

If the pavement shows obvious signs of distress, then this rating may have to be adjusted downward at the discretion of the airport authority. If the rating is lowered, then one or more of the airplanes will have ACNs that exceed the assigned rating. This may require a restriction in allowable gross weight for those airplanes or consideration of pavement strengthening. The rating could also be adjusted upward, depending on the performance of the pavement under the current traffic.

1.3 Using Airplane Example for Rigid Pavements. The following example illustrates the *Using* airplane PCN process for rigid pavements:

An airport has a rigid (concrete-surfaced) pavement runway with a subgrade modulus strength of k=200 pci and traffic having the operating gross weights and ACNs shown in Table A2-2.

Table A2-2. ***Using*** **Airplane and Traffic for a Rigid Pavement**

Airplane	Operating Weight, lbs	Tire Pressure (psi)	% GW Main Gear For ACN	ACN R/C	Annual Departures
B727-200	185,000	148	96.00	56	400
B737-300	130,000	195	90.86	38	6,000
A319-100	145,000	196	92.60	42	1,200
B747-400	820,000	200	93.32	68	3,000
B767-300ER	370,000	190	92.40	58	2,000
DC8-63	330,000	194	96.12	62	800
A300-B4	370,000	205	94.00	67	1,500
B777-200	600,000	215	95.42	77	300

- Since this is a rigid pavement, the pavement type code is *R*, (Table 2-1).
- The subgrade strength under the pavement is k=200 pci, which is *Low*, *Code C* (Table 2-2).
- The highest tire pressure of any airplane in the traffic mix is 215 psi, which is in the *X* category, as found in Table 4-2. However, since concrete can normally tolerate substantially higher tire pressures, the rating should be assigned as *W*.
- From the above list, the critical airplane is the B777-200, since it has the highest ACN of the group at the operational weights shown (77/R/C). However, the critical airplane could also be the A300-B4 at ACN 67/R/C or the B747-400 at ACN 68/R/C in that these airplanes have higher frequencies than the B777.
- Since there was no engineering analysis done in this example, and the rating was determined simply by examination of the current airplanes using the runway, the evaluation code from paragraph 4.5e is *U*.
- Based on the results of the previous steps, the pavement should tentatively be rated as PCN 77/R/C/W/U in order to accommodate all of the current traffic.
- If the pavement shows obvious signs of distress, then this rating may have to be adjusted downward at the discretion of the airport authority. If the rating is lowered, then one or more of the airplanes will have ACNs that exceed the assigned rating. This may require a restriction in allowable gross weight for those airplanes or consideration of pavement strengthening. The rating could also be adjusted upward, depending on the performance of the pavement under the current traffic.

2.0 The Technical Evaluation Method. The *Technical* evaluation method of determining PCN should be used when there is reliable knowledge of the existing traffic and pavement characteristics. Although the *Technical* evaluation provides a good representation of existing conditions, the airport authority should still be somewhat flexible in its application in that there are not only many variables in the pavement structure, but also in the method of analysis itself. The objective of the technical method is to determine a critical airplane allowable gross weight in order to assess the PCN.

2.1 Technical Evaluation for Flexible Pavements. A summary list of the steps required for flexible pavements as based on the *Technical* evaluation method is as follows:

- Determine the traffic volume in terms of type of airplane and number of operations of each airplane that the pavement will experience over its life.
- Convert that traffic into a single critical airplane equivalent.
- Determine pavement characteristics, including the subgrade CBR and pavement thickness.
- Calculate the maximum allowable gross weight of the critical airplane on that pavement.
- Calculate the ACN of the critical airplane at its maximum allowable gross weight.
- Assign the PCN to be the ACN of the critical airplane.

Details of the steps required for flexible pavements as based on the *Technical* evaluation method are listed below. Although these steps appear to be quite voluminous in their application, they are very straightforward when followed to their conclusion. Several examples are presented at the end of this section that will further explain the process describe below:

1. Determine the traffic volume in terms of traffic cycles for each airplane that has used or is planned to use the airport during the pavement life period. All significant traffic, including non-scheduled, charter, and military, should be recorded as accurately as possible. This includes traffic that has occurred from the original construction or last overlay, until the next planned overlay or reconstruction. If the pavement life is unknown or undetermined, assume that it will include a reasonable period of time. Normal flexible pavement design life is 20 years. However, the expected life can vary depending on the existing pavement conditions, climatic conditions, and maintenance practices.

   The information necessary for the traffic volume process is:
   - Past, current, and forecasted traffic cycles of each significant airplane.
   - Operational or maximum gross weights.
   - Typical airplane weight distribution on the main and nose gear. If unknown, it is generally sufficient to use 95% weight on the main gear.
   - Main gear type (dual, dual tandem, etc.).
   - Main gear tire pressure.
   - The pass-to-coverage (P/C) ratio of each airplane that might be considered as critical.
   - Fuel loading practices of airplanes at the airport.
   - Type of taxiway system - parallel or central.

2. Determine which airplane in the traffic mix from step 1 is critical or the most significant. This is required because the ACN procedure implemented in the COMFAA program is

able to accommodate only one airplane at a time. The critical airplane is the one which has the greatest pavement thickness requirements based on its individual gross weight, traffic volume, P/C ratio, and tire pressure, and it is not necessarily the one with the highest ACN or the highest gross weight.

3. The COMFAA program calculates pavement thickness requirements based on coverages rather than traffic cycles or passes. It is therefore a requirement to convert these types of frequencies to coverages by using a pass-to-coverage ratio. Airplane specific P/C ratios on flexible pavement can be calculated in the COMFAA program.

4. Using the conversion factors of Table A1-5, group the traffic volume of each airplane in the traffic mix to the critical airplane equivalent based on gear configuration differences. For example, if the critical airplane has a dual tandem gear, then all single wheel, dual wheel, and triple dual tandem wheel gears need to be converted into the dual tandem gear equivalent.

5. Determine the critical airplane equivalent traffic cycles based on the single wheel load magnitude of each airplane in the traffic mix. These calculations should be based on Equation A1-4.

6. Calculate the critical airplane TC/C ratio from Equation A1-1 for the type of taxiway and the fuel loading method. This will allow the COMFAA program to determine coverages from the critical airplane equivalent traffic cycles of Step 5.

7. From field data or construction drawings, document the average CBR of the subgrade soil. Alternatively, conduct field or laboratory tests of the subgrade soil in order to determine the CBR. Accurate portrayal of the subgrade CBR value is vital to the *Technical* method in that a small variation in CBR could result in a disproportionately large variation in the critical airplane allowable gross weight and the corresponding PCN.

8. Determine the total pavement thickness and cross sectional properties. The thickness of the pavement section under consideration must be referenced to a standard pavement section for evaluation purposes. The standard section is the total thickness requirement calculated by the COMFAA program assuming minimum layer thickness for the asphalt surface, minimum base layer thickness of material with a CBR 80 or higher and a variable subbase layer with a CBR 20 or greater. If the pavement has excess material or improved materials, the total pavement thickness may be increased according to the methods described in paragraph 321 of AC 150/5320-6D. The pavement is considered to have excess asphalt, which can be converted to extra equivalent thickness when the asphalt thickness is greater than the minimum thickness of asphalt surfaced required for the critical airplane. Minimum asphalt surface course thickness requirements are 4 inches for standard body jet transport airplanes and 5 inches for widebody airplanes. The pavement may also be considered to have excess base thickness when the cross section has a base thickness greater than the minimum specified in Table 3-4 of AC 150/5320-6D or when other improved materials such as asphalt stabilization or cement treated materials are present. Likewise, additional subbase thickness or improved subbase materials may also be converted to additional total pavement thickness.

9. With the equivalent traffic and TC/C ratio of the critical airplane, the equivalent pavement thickness, and the average CBR of the subgrade, compute the maximum allowable gross weight of the critical airplane using the COMFAA program in the pavement design mode.

10. Assign the subgrade CBR strength found in Step 7 to the appropriate standard ACN/PCN subgrade code as given in Table 2-2.

11. The ACN of the critical airplane may now be determined from the COMFAA program using the ACN mode. Enter the allowable gross weight of the critical airplane, and calculate the ACN based on the standard subgrade code of Step 10. Alternatively, consult an *ACN versus Gross Weight* chart as published in the manufacturer's *Airplane Characteristics for Airport Planning* manuals.

12. Assign the tire pressure code based on the highest tire pressure in the traffic mix from Table 2-4. Keep in mind the quality of the asphalt surface layer, as discussed in Section 2.1, when assigning this code.

13. The evaluation method is *Technical*, with a code of *T*, as described in paragraph 4.5e.

14. The numerical value of the PCN is the same as the numerical value of the ACN of the critical airplane just calculated in Step 11.

15. If the calculated allowable gross weight of Step 11 is equal to or greater than the critical airplane operational gross weight required for the desired pavement life, then the pavement is capable of handling the predicted traffic for the time period established in the traffic forecast. Accordingly, the assigned PCN of Step 14 is sufficient. If the allowable gross weight from Step 11 is less than the critical airplane gross weight required for the desired pavement life, then the pavement may be assigned a PCN equal to the ACN of the critical airplane at that gross weight, but with a lower expected pavement life. Additionally, it may then be necessary to develop a relationship of allowable gross weight based on the assigned PCN versus pavement life. Any overload should be treated in terms of ACN and equivalent critical airplane operations per individual operation. Allowance for the overload should be negotiated with the airport authority, since pre-approval cannot be assumed. Specific procedures on how to relate pavement life and gross weight for flexible pavements are found in Appendix 3 of this document.

2.2 Technical Evaluation Examples for Flexible Pavements. Four examples are presented which help explain the *Technical* Evaluation method PCN process for flexible pavements. The first example is for an under strength pavement which has traffic volume that has increased to such a level that pavement life is reduced from the original design. The second example pavement has more than adequate strength to handle the forecasted traffic. The third example pavement is the same as the second, except that the runway has a central rather than a parallel taxiway. Example 4 discusses the effect on pavement life of a higher PCN rather than a reduced allowable gross weight.

a. Flexible Pavement Example 1. An airport has a flexible (asphalt-surfaced) runway pavement with a subgrade CBR of 9 and a total thickness of 32.0 inches, shown in Figure A2-1 (5 inch minimum asphalt surface layer, 8 minimum base layer and variable subbase layer).

Additional fuel is generally obtained at the airport before departure, and the runway has a parallel taxiway. The pavement was designed for a life of 20 years. It is assumed for the purposes of this example that the traffic level is constant over the 20-year time period. The traffic is shown in Table A2-3, and it is the same as in Table A2-1, but with additional information added.

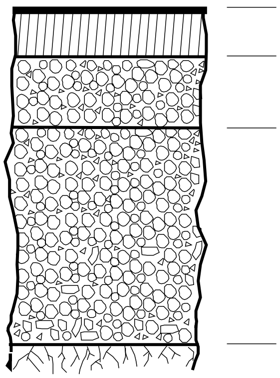

Figure A2-1. Flexible Pavement Example Cross Section

Table A2-3. Technical Evaluation Critical Airplane Determination

Airplane	Operating Weight, (lbs)	Tire Pressure (psi)	ACN F/B	Annual Departures	Flexible **P/C	Required t, (in.)
B727-200	185,000	148	48	400	2.92	22.6
B737-300	130,000	195	35	6,000	3.79	22.7
A319-100	145,000	196	35	1,200	3.18	20.3
B747-400	**820,000**	**200**	**59**	**3,000**	**1.73**	**30.9**
B767-300ER	370,000	190	52	2,000	1.80	27.9
DC8-63	330,000	194	52	800	1.68	26.6
A300-B4	370,000	205	57	1,500	1.44	29.3
B777-200	600,000	215	51	300	1.42	28.0

** P/C determined at 95% of gross load on main gear

The required total pavement thickness results are shown in Table A2-3 for each airplane. It can be seen that the B747-400 airplane has the greatest individual pavement thickness requirement (30.9 inches) for its total traffic over 20 years, and it is therefore the critical airplane. Note that the thickness requirements for each individual airplane are less than the existing pavement thickness of 32.0 inches.

Table A2-4 shows the conversion of departures of the other traffic to the critical airplane 747-400 equivalent. As previously discussed, all widebody wheel loads were considered to be that of a 300,000-lb dual tandem airplane, or 35,625 lb, including the critical airplane. Gear configuration conversion factors from Table A1-5 were utilized to determine the equivalent dual tandem gear departures. The B747-400 equivalent annual departures were calculated by using Equation A1-4. Although the B747-400 had only 3,000 annual departures, the effect of the other traffic has increased the number to an equivalent 11,250.

Note that the equivalent annual departure total shown would also be the same for the 767-300ER and the A300-B4 because the assumed wheel loads are the same as that of the critical airplane. This would not be true, however, for the 777-200 because of the different gear configuration. Note also the effect of wheel load on the critical airplane equivalent annual departures. Wheel loads of the individual airplanes that are greater than the critical airplane wheel load add to the critical airplane equivalent departures by a factor greater than one, while wheel loads that are less add by a factor less than one. This relationship indicates the need to carefully consider the loading of each airplane in the traffic mix in determining equivalent traffic.

Table A2-4. Equivalent Annual Departures of the Critical Airplane

Airplane	Annual Departures	Gear Type	(R_2) Equiv. (2D) Departures	(W_2) Wheel Load (lbs)	(W_1) 747-400 Wheel Load (lbs)	(R_1) 747-400 Equiv. Ann. Departures
B727-200	400	D	240	43,940	35,625	473
B737-300	6,000	D	3,600	30,875	35,625	2,172
A319-100	1,200	D	720	34,440	35,625	687
B747-400	3,000	2D/2D2	3,000	35,625	35,625	3,000
B767-300ER	2,000	2D	2,000	35,625	35,625	2,000
DC8-63	800	2D	800	39,190	35,625	1,109
A300-B4	1,500	2D	1,500	35,625	35,625	1,500
B777-200	300	3D	510	35,625	35,625	469
	15,200					11,410

With the total equivalent traffic of the critical airplane known, the traffic cycle ratio for the taxiway and fuel situation can be calculated. Following the example shown in Table A1-2 and based on Equation A1-1, for a critical airplane P/C ratio of 1.73 and a P/TC ratio of 1 for a parallel taxiway, the traffic cycle to coverage ratio is:

$$TC/C = 1.73 \div 1 = 1.73$$

It is now possible to calculate the maximum allowable gross weight of the 747-400 critical airplane on this pavement. The input parameters to the COMFAA program are:

Critical airplane	747-400
Pavement thickness	32.0 inches

Subgrade CBR	9.0 (Code *B*)
Tire pressure	200 psi (Code *X*)
Percent Weight on the main gear	95.0 %
TC/C ratio	1.73
Pavement life	20 years
Annual equivalent departures	11,410
Total Coverages (TC/1.73) x 20	131,908

For these conditions, from the COMFAA program, the calculated allowable gross weight of the B747-400 is 771,000 pounds. From the COMFAA program, the B747-400 ACN at this weight is 53.8/F/B, for a recommended pavement rating of PCN 54/F/B/X/T.

Referring to Table A2-3, it can be seen that the 747-400 and the A300-B4 airplane would be restricted in their operations on this runway due to their ACNs of 59/F/B and 57/F/B, respectively, being higher than the recommended PCN of 54/F/B. It is apparent from this result that the pavement is not adequate to handle the existing traffic, and either the operating weights will have to be restricted or pavement life will be less than originally expected. An analysis of this situation and the requirements for adjustments is provided in Appendix 3.

b. Flexible Pavement Example 2. This second example has the same input parameters as the first, except that the pavement cross-section is increased to 36 inches.

The input parameters to the COMFAA program for this example are:

Critical airplane	B747-400
Pavement thickness	36.0 inches
Subgrade CBR	9.0 (Code *B*)
Tire pressure	200 psi (Code *X*)
Percent Weight on the main gear	95.0 %
TC/C ratio	1.73
Pavement life	20 years
Annual equivalent departures	11,410
Total Coverages (TC/1.73) x 20	131,908

For these conditions, the calculated allowable gross weight of the 747-400 is 893,000 pounds. From the COMFAA program, the B747-400 ACN at this weight is 66.1/F/B, for a recommended rating of PCN 66/F/B/X/T.

It can be seen from an examination of Table A2-3 that all of the traffic has ACNs that are less than the recommended PCN. It can therefore be safely assumed that the pavement will adequately handle the existing traffic within its design life, and no adjustments to the pavement cross section or life will have to be made. Note that the addition of 4 inches in pavement thickness from Example 1 has resulted in a net increase in PCN of 12.0.

c. Flexible Pavement Example 3. The only change in this example from the second example is that the taxiway is a central configuration rather than parallel, such as shown in Figure

3-1b. Referring to Table 3-4, the P/TC ratio changes from 1 to 2. From Equation 3-2, the TC/C ratio for the critical 747-400 airplane becomes:

TC/C = 1.73 ÷ 2 = 0.865

The input parameters to the COMFAA program are:

Critical airplane	B747-400
Pavement thickness	36.0 inches
Subgrade CBR	9.0 (Code *B*)
Tire pressure	200 psi (Code *X*)
Percent Weight on the main gear	95.0 %
TC/C ratio	0.86
Pavement life	20 years
Annual equivalent departures	11,410
Total Coverages (TC/0.865) x 20	263,815

For these conditions, the calculated allowable gross weight of the 747-400 is 847,000 pounds. From the COMFAA program, the B747-400 ACN at this weight is 61.3/F/B, for a recommended runway rating of PCN 61/F/B/X/T. The net effect of the change in taxiway configuration from that of Example 2 is the reduction in PCN by 5.

d. Flexible Pavement Example 4. As an alternate way of looking at the effect of a parallel versus central taxiway effects, consider how the pavement life would change instead of the PCN. If the PCN from Example 2 were to remain at 66/F/B/X/T, which is equivalent to a 747-400 critical airplane allowable gross weight of 893,000 pounds, then the pavement life would be reduced from 20 to 10 years. This is due to the change in the TC/C ratio from 1.72 to 0.86. A similar effect would be noticed if the fuel situation were to be changed to *not* obtaining fuel at the airport, rather than as proposed in the first flexible pavement example case. These changes in pavement life would need to be acceptable to the airport authority.

2.3 Technical Evaluation for Rigid Pavements. A summary list of the steps required for rigid pavements as based on the *Technical* evaluation method is as follows:

1. Determine the traffic volume in terms of type of airplane and number of operations of each airplane that the pavement will experience over its life.

2. Convert that traffic into a single critical (design) airplane equivalent.

3. Determine the pavement characteristics; including subgrade soil modulus, k, and the concrete thickness and elastic modulus.

4. Calculate the maximum allowable gross weight of the critical airplane on that pavement.

5. Look up or calculate the ACN of the critical airplane at its maximum allowable gross weight, as determined in the previous step.

6. Assign the PCN to be the ACN just calculated.

Details of the steps for rigid pavements as based on the *Technical* evaluation method are:

1. Determine the traffic volume in the same fashion as noted in paragraph A2-2.1 for flexible pavements

2. Determine which airplane in the traffic mix from step 1 is critical or the most significant. The critical airplane is the one which has the greatest pavement thickness requirements based on its individual gross weight, traffic volume, P/C ratio, and tire pressure, and it is not necessarily the one with the highest ACN or the highest gross weight.

3. The PCA rigid design procedure implemented in the COMFAA program calculates pavement thickness requirements based on the concrete edge stress, which is in turn dependent on load repetitions of the total traffic mix. It is therefore a requirement to convert traffic cycles or passes to load repetitions by using a pass-to-load repetition ratio. P/C ratios for any airplane on rigid pavement are calculated in the COMFAA program.

4. Using the conversion factors of Table A1-5, group the traffic volume of each airplane in the traffic mix to the critical airplane equivalent based on gear configuration differences.

5. Determine the critical airplane equivalent traffic cycles based on the single wheel loads of each airplane in the traffic mix using Equation A1-4.

6. Calculate the critical airplane TC/C ratio from Equation A1-2 for the type of taxiway and the fuel loading method.

7. Using the critical airplane equivalent traffic cycles from Step 5 and the TC/C ratio from Step 6, calculate the equivalent load repetitions of the critical airplane based on the life expectation of the pavement.

8. Obtain the pavement characteristics including the concrete slab thickness, the concrete modulus of rupture, and average modulus, k, of the subgrade. Concrete elastic modulus is set at 4,000,000 psi and Poisson's ratio is set at 0.15 in the COMFAA program. Accurate subgrade modulus determination is important to the *Technical* method, but small variations in the modulus will not affect the PCN results in a disproportionate manner. This is in contrast to flexible pavement subgrade modulus in which strength variations have a significant effect on PCN. If the pavement has a subbase course and or stabilized subbase layers, then the subgrade modulus is adjusted upwards to an equivalent value in order to account for the improvement in support. Subgrade modulus adjustments are made from figures 2-4 and 3-16 of AC 150/5320-6D.

9. With the known slab thickness, subgrade modulus, and airplane parameters compute the maximum allowable gross weight of the critical airplane using the COMFAA

program in the pavement design mode. By setting the airplane total coverages, gross airplane weight can be adjusted until the known pavement thickness is achieved.

10. Assign the subgrade modulus (k-value) to the nearest standard ACN/PCN subgrade code. The k-value to be reported for PCN purposes is the improved k-value seen at the top of all improved layers. Subgrade codes for k-value ranges are found in Table 2-2.

11. The ACN of the critical airplane may now be determined from the COMFAA program. Enter the allowable gross weight of the critical airplane from Step 9, and calculate the ACN for the standard subgrade code of Step 10. Alternatively, consult an *ACN versus Gross Weight* chart as published in the manufacturer's *Airplane Characteristics for Airport Planning* manuals.

12. Assign the tire pressure code based on the highest tire pressure in the traffic mix from Table 2-4. As discussed previously, rigid pavements are typically able to handle high tire pressures, and usually Code W can be assigned.

13. The evaluation method is *Technical*, with a code of *T*, as described in paragraph 4.5e.

14. The numerical value of the PCN is the same as the numerical value of the ACN of the critical airplane just calculated in Step 11.

15. If the allowable gross weight of Step 11 is equal to or greater than the critical airplane operational gross weight required for the desired pavement life, then the pavement is capable of handling the predicted traffic for the time period established in the traffic forecast. Accordingly, the assigned PCN of Step 12 is sufficient. If the allowable gross weight from Step 11 is less than the critical airplane gross weight required for the desired pavement life, then the pavement may be assigned a PCN equal to the ACN of the critical airplane at that gross weight, but with a reduced pavement life. Additionally, it may then be necessary to develop a relationship of allowable gross weight based on the assigned PCN versus pavement life. Procedures on how to relate pavement life and gross weight for rigid pavements in terms of PCN are found in Appendix 3. Any overload should be treated in terms of ACN and equivalent critical airplane operations per individual operation. Allowance for the overload should be negotiated with the airport authority, since pre-approval cannot be assumed. Specific procedures on how to relate pavement life and gross weight for rigid pavements are found in Appendix 3.

2.4 Technical Evaluation Examples for Rigid Pavements. Three examples are presented which help explain the *Technical* Evaluation method PCN process for rigid pavements. The first example pavement is under designed in that the traffic volume has increased to such a level that pavement life is reduced from the original design. The second pavement has more than adequate strength to handle the forecasted traffic. The third example pavement is the same as number two, except that the airplanes generally do not obtain fuel at the airport.

a. Rigid Pavement Example 1. An airport has a rigid (concrete-surfaced) runway pavement with an effective subgrade k-value of 200 pci and a slab thickness of 14 inches, as shown in Figure A2-2. The concrete has a modulus of rupture is 700 psi, an elastic modulus of 4,000,000 psi, and a Poisson's ratio of 0.15. The runway has a parallel taxiway, and additional fuel is generally obtained at the airport before departure. The pavement life is estimated to be 20 years from the original construction. The traffic shown in Table A2-5 is basically the same as in Table A2-1, but with P/C ratios and life load repetitions added.

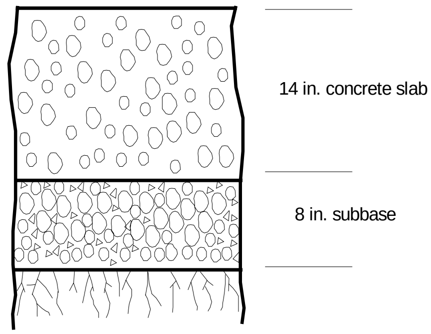

Figure A2-2. Rigid Pavement Example Cross Section

The critical airplane will be the one with the highest required thickness for its load magnitude and frequency. The thickness required for each airplane is determined with the COMFAA program in the pavement design mode. The load repetitions must first be calculated for each airplane by using Equation A1-1 and then converted to coverages for use in the COMFAA program. Since additional fuel is generally obtained at the airport, and there is a parallel taxiway, then:

P/TC = 1
TC/C = P/C
Coverages (C) = annual departures $*$ 20 years $\div$ TC/C

The resulting coverages are listed for each airplane in Table A2-5. The thickness of rigid pavement required for each airplane at the operating weight and frequency are shown in Table A2-6.

Table A2-5 Rigid Pavement *Technical* Evaluation Traffic

Airplane	**Operating Weight, lbs**	**Tire Pressure (psi)**	**ACN (R/C)**	**** P/C**	**Annual Departures**	**Coverages**
B727-200	185,000	148	55	2.92	400	2,740
B737-300	130,000	195	38	3.79	6,000	31,662
A319-100	145,000	173	42	3.18	1,200	7,547
B747-400	820,000	200	68	3.46	3,000	17,341
B767-300ER	370,000	190	58	3.60	2,000	11,111

DC8-63	330,000	194	62	3.35	800	4,776
A300-B4	370,000	205	67	3.49	1,500	8,595
B777-200	600,000	215	77	4.25	300	1,412

** Rigid P/C determined at 95% of gross load on main gear

Table A2-6 shows that the critical airplane is the 747-400, based on its required thickness. However, the A300-B4 should also be given consideration as critical in that its required thickness is very close to that of the 747-400. In this example, the 777-200 is not the critical airplane, even though it has the highest ACN.

Table A2-6. *Technical* Evaluation Critical Airplane Determination

Airplane	Operating Weight, lb	Required Thickness (in.)
727-200	185,000	13.0
737-300	130,000	13.2
A319-100	145,000	11.1
747-400	**820,000**	**14.1**
767-300ER	370,000	12.8
DC8-63	330,000	12.5
A300-B4	370,000	13.6
777-200	600,000	11.5

Table A2-7. Equivalent Annual Departures of the Critical Airplane

Airplane	Annual Departures	Gear Type	(R_2) Equiv. (2D) Departures	(W_2) Wheel Load	(W_1) 747-400 Wheel Load	(R_1) 747-400 Equiv.Ann. Departures
727-200	400	D	256	43,940	35,625	473
737-300	6,000	D	3,840	30,875	35,625	2,172
A319-100	1,200	D	768	34,440	35,625	687
747-400	**3,000**	**2D/2D2**	**3,000**	**35,625**	**35,625**	**3,000**
767-200ER	2,000	2D	2,000	35,625	35,625	2,000
DC8-63	800	2D	800	39,190	35,625	1,109
A300-B4	1,500	2D	1,500	35,625	35,625	1,500
777-200	300	3D	468	35,625	35,625	469
	15,200					11,410

All departures of the other traffic must be converted to the 747-400 equivalent as shown in Table A2-7. For the purposes of this calculation, all widebody wheel loads are considered to be 35,625 lb, including the critical airplane. Note that this table is identical to Table A2-4 for the flexible pavement examples.

Before the maximum allowable gross weight of the critical airplane can be determined from the COMFAA program, the anticipated traffic reported in annual departures must be converted to total coverages (lifetime coverages). As stated previously, since additional fuel is generally obtained at the airport, and there is a parallel taxiway, then:

P/TC = 1
P/C = 3.46
TC/C = 3.46
Coverages = 11,410 * 20 years ÷ 3.46 = 65,954

The input parameters to the COMFAA program (pavement design mode) are:

Critical airplane	747-400
Coverages	65,954
Percent weight on the main gear	95.0 %
Tire pressure	200 psi (Code *X*) tire contact area 260.4 sq. in.
Slab thickness	14.0 inches
Slab flexural strength	700 psi
Subgrade k-value	200 pci (Code *C*)

For these conditions, the COMFAA program can be used to iterate to a solution by adjusting the gross airplane weight until the known pavement thickness is obtained. For this example, the calculated allowable gross weight of the 747-400 is 741,000 pounds. By switching the COMFAA program back to the ACN mode and entering in the allowable gross weight, an ACN of 59.0/R/C is obtained for the 747-400. The final recommended runway rating is PCN 59/R/C/W/T. As mentioned in Section 2, even though none of the airplanes in this example have tire pressures that exceed the limits of Code *X*, the code for rigid pavement should normally be *W*.

Referring to Table A2-5, it can be seen that the 747-400, the DC8-63, the A300-B4, and the 777-200 airplane would be restricted in their operations on this runway due to their ACNs of 68/R/C, 62/R/C, 67/R/C and 77/R/C, respectively, being higher than the derived PCN of 59/R/C. It is apparent from this result that the pavement is not adequate to handle the existing traffic, and either the operating weights will have to be restricted or pavement life will be less than originally expected. An analysis of this situation and the requirements for adjustments is explained in Appendix 3.

b. Rigid Pavement Example 2. This second example has the same input parameters as the first, except that the slab thickness is increased to 16 inches. The input parameters to the COMFAA program are:

Critical airplane	747-400
Coverages	65,954
Percent weight on the main gear	95.0 %
Tire pressure	200 psi (Code *X*) tire contact area 260.4 sq. in.
Slab thickness	16.0 inches
Subgrade k-value	200 pci (Code *C*)
Concrete flexural Strength	700 psi

For these conditions, the calculated allowable gross weight of the 747-400 is 865,000 pounds. The 747-400 ACN is 73.2/R/C, for a recommended runway rating of PCN 73/R/C/W/T.

It can be seen from Table 4-5 that all of the traffic except the B777-200 have ACNs that are less than the recommended PCN. It can therefore be safely assumed that the pavement will adequately handle the existing traffic, with operational weight limitation on the B777-200, within its design life, and no adjustments to the pavement cross section or life will have to be made.

c. Rigid Pavement Example 3. The only change in this example from the second example is that the airplanes generally do not obtain fuel at the airport. Referring to Table A1-3, the P/TC ratio changes from 1 to 2. From Equation A1-2, the TC/C ratio for the critical 747-400 airplane becomes:

$$TC/C = 3.46 \div 2 = 1.73$$

Where:

P/TC = 2
P/C = 3.46

Therefore, lifetime coverages = 11,410 $*$ 20 years ÷ 1.73 = 131,908

The input parameters to the COMFAA program in pavement thickness mode are:

Critical airplane	747-400
Coverages	131,908
Percent weight on the main gear	95.0 %
Tire pressure	200 psi (Code *X*) tire contact area 260.4 sq. in.
Slab thickness	16.0 inches
Subgrade k-value	200 (Code *C*)
Concrete Flexural Strength	700 psi

For these conditions, the calculated allowable gross weight of the 747-400 is 828,000 pounds. The 747-400 ACN is 68.9/R/C, for a recommended runway rating of PCN 69/R/C/W/T. This rating would require small weight restrictions on the B777 airplane. However since additional full is not obtain, the landing weight is most likely already below the possible restriction.

APPENDIX 3. Pavement Overload Evaluation by the ACN-PCN system

1.0 ICAO Pavement Overload Evaluation Guidance. In the life of a pavement, it is possible that either the current or future traffic will load the pavement in such a manner that the assigned pavement rating is exceeded. ICAO presents a simplified method to account for minor pavement overloading in which the overloading may be adjusted by applying a fixed percentage to the existing PCN. The ICAO procedure for overload operations is based on minor or limited traffic having ACNs that exceed the reported PCN. Loads that are larger than the defined PCN will shorten the pavement design life, while smaller loads will use up the life at a reduced rate. With the exception of massive overloading, pavements in their structural behavior do not suddenly or catastrophically fail. As a result, occasional minor airplane overloading is acceptable with only limited loss of pavement life expectancy and relatively small acceleration of pavement deterioration. For those operations in which the magnitude of overload and/or frequency does not justify a detailed (technical) analysis, the following criteria are suggested.

- For flexible pavements, occasional traffic cycles by airplanes with an ACN not exceeding 10 percent above the reported PCN should not adversely affect the pavement.
- For rigid or composite pavements, occasional traffic cycles by airplanes with an ACN not exceeding 5 percent above the reported PCN should not adversely affect the pavement.
- The annual number of overload traffic cycles should not exceed approximately 5 percent of the total annual airplane traffic cycles.
- Overloads should not normally be permitted on pavements exhibiting signs of distress or failure, during any periods of thaw following frost penetration, or when the strength of the pavement or its subgrade could be weakened by water.
- Where overload operations are conducted, the airport authority should review the relevant pavement condition on a regular basis and should also review the criteria for overload operations periodically, since excessive repetition of overloads can cause severe shortening of pavement life or require major rehabilitation of the pavement.

However, this gives little guidance to the airport authority as to the impact of these overload operations on the pavement in terms of pavement life reduction or increased maintenance requirements. Appendix 3 will present methods for making overload allowances for both flexible and rigid pavements that will clearly indicate these effects and will give the authority the ability to determine the impact both economically and in terms of pavement life.

1.1 Overload Guidance. The overload evaluation guidance in Appendix 3 applies primarily to pavements that have PCN values that were established by the *Technical* method. Pavements that have ratings determined by the *Using* airplane method can use the overload guidelines provided by ICAO. The procedures in Appendix 3 rely on the COMFAA program. Procedures for flexible and rigid pavement are discussed and examples provided.

The adjustments for pavement overloads start with the assumption that some of the airplanes in the traffic mix have ACNs that exceed the PCN. If the steps outlined in Appendix 2 have been followed for the *Technical* method, then most of the necessary data already exists to perform an examination of overloading.

For flexible pavement, referring to the first example of Appendix 2, it was found that the B747-400 and A300-B4 airplanes have ACNs that exceed the recommended runway rating. Likewise, for rigid example number 1, the ACNs of the B747-400, A300B4, DC8-63, and B777-200 exceed the recommended runway rating. Individually, none of the airplanes in the traffic mix have requirements that exceed the existing pavement thickness requirements. However, an anomaly is created in that each of these airplanes were included in the derivation of the allowable gross weight of the critical airplane. This, in turn, led to the recommendation of a PCN that was not adequate for the larger airplanes. To resolve these kinds of problems the airport authority will have three options on their pavement strength rating selection:

Let the PCN remain as derived from the *Technical* evaluation method, but retain local knowledge that there are some airplanes in the traffic mix that can be allowed to operate with ACNs that exceed the published PCN or at a reduced weight to not exceed the PCN.

Provide for an increased PCN by either adding an overlay or by reconstruction in order to accommodate airplanes with the higher ACNs.

Adjust the PCN upward to that of the airplane with the highest ACN, but recognize the need to expect possible severe maintenance. This will result in earlier than planned reconstruction or overlay due to reduced pavement life.

The first option requires that the airport authority constantly be aware of the composition of the entire traffic mix in terms of operating gross weights and loading frequency. If the traffic mix has changes that affect the factors involved in developing a technically based PCN, then the PCN will need to be adjusted to reflect the changes. The airport authority will also have to internally make allowance for or prevent airplane operations that exceed the PCN. The difficulty in doing so is that the magnitude of the PCN is out of step with the ACNs of some of the traffic.

The second option alleviates the problems discussed for the first option, but it does require additional expense to bring the pavement up to the strength required by the combination of airplanes in the traffic mix. Doing so will, however, allow operations at the required strength and for the desired pavement life.

The third option has the benefit of allowing all airplanes in the traffic mix to operate as necessary. However, by increasing the PCN, which implies higher pavement strength, the pavement life will be reduced unless an increase in thickness is provided.

Each of these options is considered in the following discussion on pavement overloading, first for flexible pavement and then for rigid pavement.

1.2 Adjustments for Flexible Pavement Overloads. It is most efficient to describe the procedures for flexible pavement overloading by continuing the first flexible pavement *Technical* evaluation in example 1 of Appendix 2, in which two airplanes of the traffic mix were found to exceed the pavement capability. In this example the derived rating was found to be PCN 55/F/B/X/T, with the traffic of Table A2-3 operating on the runway.

a. Flexible Pavement Overload Illustration 1. Examination of Table A2-3 indicates that the 747-400 was operating at a gross weight of 820,000 pounds, with an ACN of

59/F/B. Likewise, the A300-B4 had a gross weight of 370,000 pounds and an ACN of 57/F/B. Reduction of the gross weights to the rated PCN of 54/F/B/X/T would result in a gross weight for the 747-400 of 771,000 pounds and a gross weight of 357,000 pounds for the A300-B4. Although these limited operating weights would solve the problem of pavement loading they have the disadvantage of restricting airline operations. Additionally, new traffic with airplanes having ACNs exceeding the PCN would also have to be restricted.

b. Flexible Pavement Overload Illustration 2. Rather than restricting operating weights, the airport could refurbish the pavement by the addition of an overlay. The computer steps for determining such a flexible pavement overlay are as follows:

- Construct an ACN versus gross weight diagram such as shown in Figure A3-1 for the 747-400 critical airplane at the subgrade code previously determined. Data for this chart may be obtained from the COMFAA program by calculating ACN at various gross weights. Note in this figure that the relationship of ACN and gross weight is not a straight line, but is slightly curved in that the line was derived by calculating the ACN at a series of gross weights, rather than just connecting the minimum and maximum values.

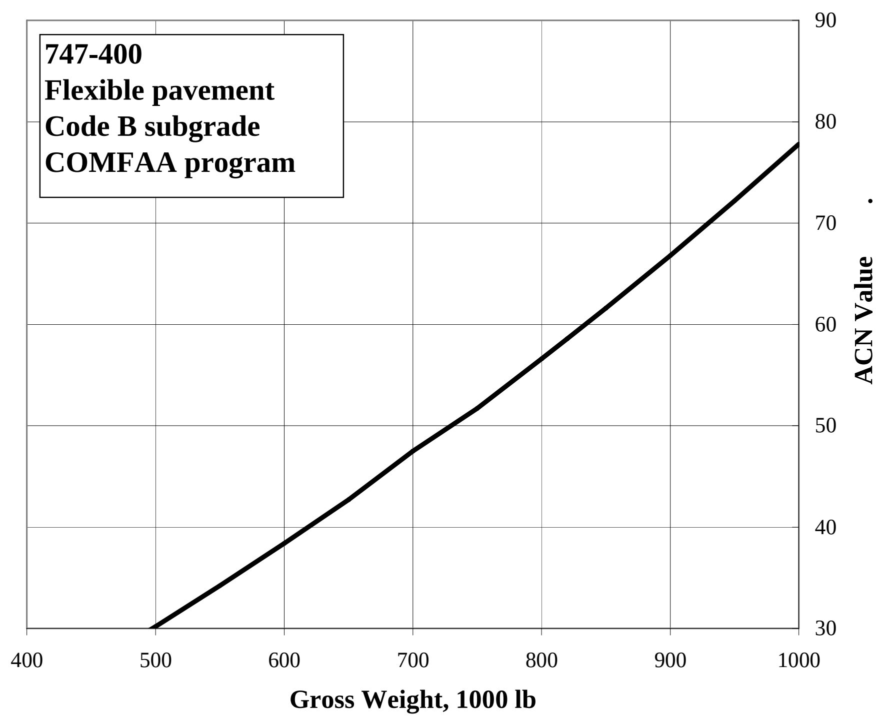

Figure. A3-1. 747-400 Flexible Pavement ACN versus Gross Weight

- Use the COMFAA program to develop data of pavement life versus ACN, such as shown in Figure A3-2. This chart is similar to that found in Section 7 of the manufacturer's *Airplane Characteristics for Airport Planning* manuals except that subgrade CBR and pavement thickness are not shown in that they are already fixed. For example, there are four basic parameters involved in pavement design:

- Subgrade CBR
- Pavement thickness
- Airplane gross weight
- Traffic volume and pavement life

Of these four, the only variables are gross weight and pavement life in terms of annual traffic cycles. By relating gross weight to ACN (as was done in Figure A3-1), ACN can be substituted on the abscissa of Figure A3-2. For each pavement life number, a gross weight is found that satisfies the subgrade CBR and pavement thickness, which is then converted to ACN. Table 5-1 contains part of the data used in the COMFAA program to construct the curves of Figure A3-2 for a 747-400 airplane with a subgrade CBR of 9.0.

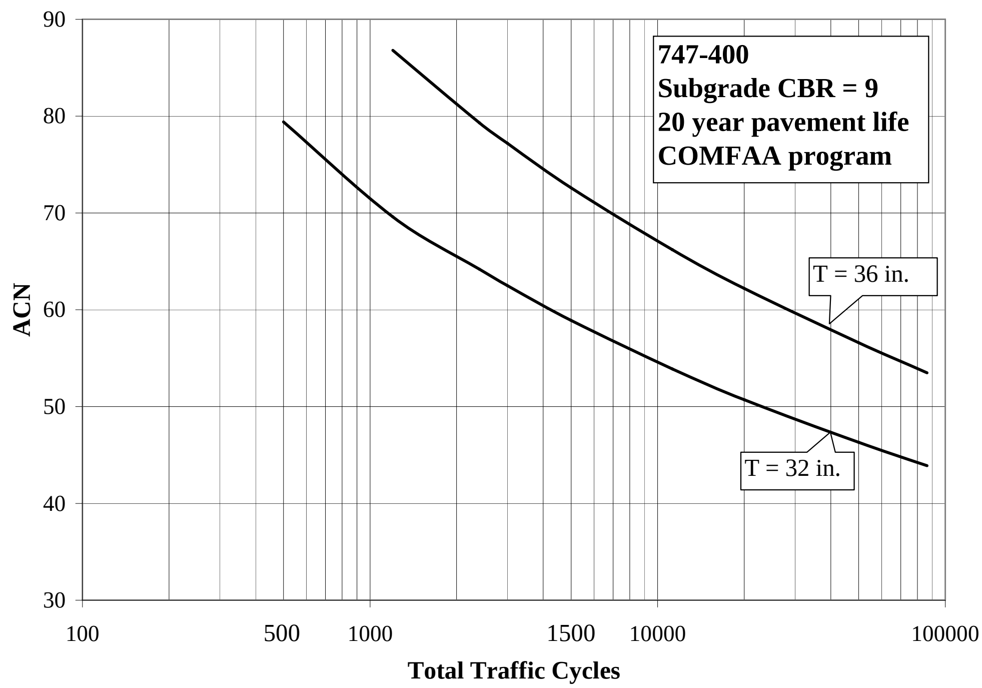

Figure A3-2. 747-400 Flexible Pavement Life versus ACN

Table A3-1. Data for Constructing Flexible Pavement Life Curves for B747-400

B747-400 Annual Departures	Coverages at (P/C = 1.73)	T=32 Gross weight	T=32 ACN	T-35 Gross weight	T=35 ACN
500	5,780	1,014,000	79.4	--	--
1200	13,873	926,000	69.6	1,075,000	86.8
2400	27,746	875,000	64.2	1,013,000	79.3
3000	34,682	858,000	62.5	994,500	77.2
5000	57,803	822,500	58.9	953,400	72.6
11410	131,908	771,000	53.8	893,000	66.1
20000	231,214	738,500	50.7	855,000	62.2
50000	578,035	690,400	46.3	800,000	56.6
86500	1,000,000	664,000	43.9	768,000	53.5

Note: Pass-to-coverage ratio determined for airplane configurations reported by airplane manufacturers when calculating ACN value (gross load, center of gravity, tire pressure).

It is now possible to relate the effects of gross weight, ACN, and pavement life by combining the two charts, as shown in Figure A3-3. The left hand side of this figure is the chart of Figure A3-1, while the right hand chart is that of Figure A3-2. It can now be seen how the critical airplane gross weight of 771,000 pounds (PCN 54/F/B/X/T) equates to 11,410 equivalent 747-400 traffic cycles per year for 20 years. If the PCN were increased to 66/F/B/X/T to accommodate the higher gross weights, the allowable traffic cycles of the critical airplane at 893,000 pounds gross weight would decrease to 1,868 per year for the 20-year time period. This effectively reduces the pavement life from 20 years to just over 3 years. (1,868 x 20 ÷ 11,410 = 3.27).

This example shows that the pavement with a thickness of 32 inches is under designed for the traffic expected over the next 20 years. It is therefore reasonable to expect that an overlay to bring the effective thickness to 36 inches will be required if the pavement is to last for the required 11,410 annual departures for 20 years. This can be seen graphically in Figure A3-3.
It can also be seen from Figure A3-3 that for any combination of critical airplane gross weight in terms of ACN, the pavement life is known. Thus, the airport authority can determine from this type of chart the allowances to be made for traffic overloading. The airport authority also now has the information necessary to make a decision on the assignment of a PCN. If the PCN is raised to a level to permit all of the current traffic, the required pavement overlay can be determined. Furthermore, the impact of the higher ACN airplane can be determined in the requirements for overlay thickness. It may be necessary to repeat this process if new airplanes are added to the traffic mix in that their effects are not accounted for in the above calculations. Likewise, if there are any other significant changes in the traffic mix, the rating should be reviewed.

The reader is reminded that this example is only intended to illustrate the effect of pavement thickness on the PCN rating and that overlay thickness requirements for pavement design purposes should be accomplished us AC 150/5320-6.

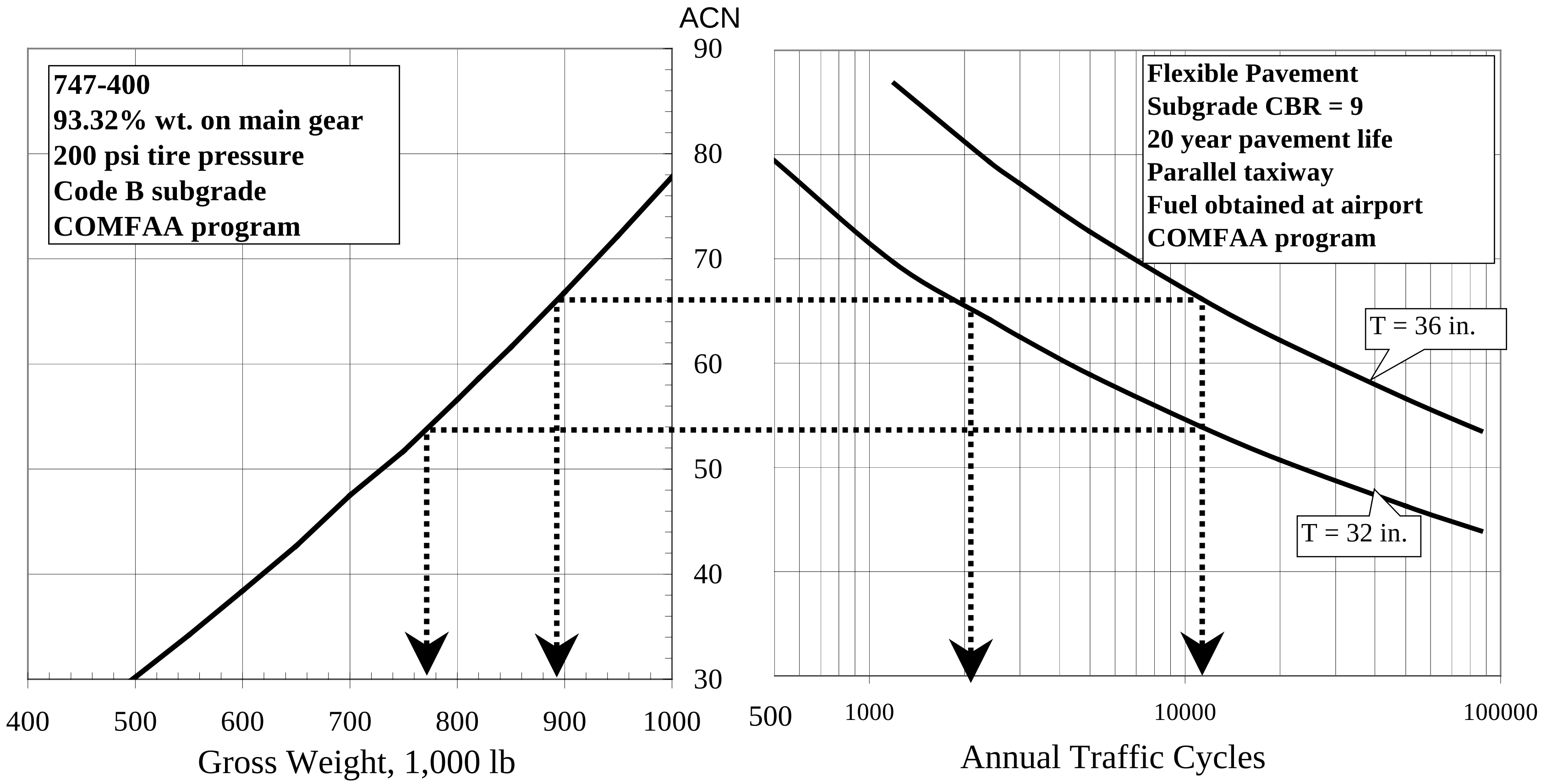

Figure A3-3. 747-400 Flexible Pavement Life

c. Flexible Pavement Overload Illustration 3. This example will illustrate the effect of ICAO allowable overloading in which the ACN is no more than 10% above the PCN and the number of traffic cycles does not exceed 5% of the total annual traffic.

Table A2-3 is repeated here as Table A3-2, but with a new airplane added to the traffic mix with an ACN that is 10% above the rated PCN of 54/F/B/X/T. The total annual departures, as shown in Table A2-4, is 15,200, of which 760 is 5% of the total. This amount is shown in Table A3-3. Normally in a calculation of critical airplane equivalent departures the W_2 wheel load would be listed as 35,625 pounds for a widebody airplane, but for the sake of illustration, the new airplane actual single wheel load is shown.

Table A3-2. Flexible Pavement Overload Airplane Added

Airplane	Operating Weight, (lbs)	Tire Pressure (psi)	ACN F/B	Annual Departures	Flexible **P/C	Required t, (in.)
B727-200	185,000	148	48	400	2.92	22.6
B737-300	130,000	195	35	6,000	3.79	22.7
A319-100	145,000	196	35	1,200	3.18	20.3
B747-400	**820,000**	**200**	**59**	**3,000**	**1.73**	**30.9**
B767-300ER	370,000	190	52	2,000	1.80	27.9
DC8-63	330,000	194	52	800	1.68	26.6
A300-B4	370,000	205	57	1,500	1.44	29.3
B777-200	600,000	215	51	300	1.42	28.0
L1011-500	456,000	184	60	760	1.80	28.3

** Flexible P/C determined at 95% of gross load on main gear

The end result on the critical airplane calculation is that for an equivalent annual departure level of 14,973, the allowable gross weight is reduced from 771,000 to 755,000 pounds for an ACN of 52.2/F/B. Alternately, for the same allowable gross weight of 771,000 pounds and an ACN of 53.8/F/B, the pavement thickness would have to be increased to 32.5 inches from the current 32.0 inches.

This example shows the impact both on required pavement thickness and on PCN of a new airplane that is within the ICAO guidelines of no more than 10% overload and no more than 5% traffic increase. With this type of knowledge as to the impact of new airplanes on pavement thickness requirements, the airport authority can make a decision as to the relative effects. Although these examples were for specific conditions as described, the methods can also be applied to any other traffic overloading condition.

Table A3-3 Flexible Pavement New Airplane Equivalent Traffic

Airplane	Annual Departures	Gear Type	(R_2) Equiv. (2D) Departures	(W_2) Wheel Load (lbs)	(W_1) 747-400 Wheel Load (lbs)	(R_1) 747-400 Equiv. Ann. Departures
B727-200	400	D	240	43,940	35,625	473
B737-300	6,000	D	3,600	30,875	35,625	2,172
A319-100	1,200	D	720	34,440	35,625	687
B747-400	3,000	2D/2D2	3,000	35,625	35,625	3,000
B767-300ER	2,000	2D	2,000	35,625	35,625	2,000
DC8-63	800	2D	800	39,190	35,625	1,109
A300-B4	1,500	2D	1,500	35,625	35,625	1,500
B777-200	300	3D	510	35,625	35,625	469
L1011-500	760	2D	760	54150	35,625	3,563
	15,960					14,973

1.3 Adjustments for Rigid Pavement Overloads. As was done for the flexible pavement overload illustration, the procedures for rigid pavement overloading can best be explained by continuing the first rigid pavement *Technical* evaluation example in Appendix 2. In this example, for which the derived PCN was 59/R/C/W/T, the B747-400, A300-B4, B777-200, and DC863 were found to exceed the pavement capability, as shown in Table A2-5. This requires that adjustments be made to allow these airplanes to operate at its desired gross weight. These adjustments can be in the form of either a reduced pavement life or an overlay to increase the pavement strength.

A second overload illustration is also presented that examines the effect of occasional traffic of airplanes having an ACN that exceeds the PCN.

a. Rigid Overload Illustration 1. Evaluation of rigid pavement overload is similar to flexible pavement. It is necessary to develop the pavement life variables first, and then examine the results with the COMFAA program. A listing of steps to be followed to determine rigid pavement overloading effects are:

1. Construct an ACN versus gross weight diagram such as shown in Figure A3-4 for the 747-400 critical airplane at the subgrade code previously determined. Note that the line relating ACN and gross weight is not straight in that it was constructed by using a selection of many points rather than just connecting the minimum and maximum values. Data for figure A3-4 can be generated in the COMFAA program by calculating ACN values at various gross weights.

2. Construct an ACN versus pavement life chart, as shown in Figure A3-5. Data for figure A3-5 can be generated by the COMFAA program by first entering the load repetitions (coverages) and adjusting the gross weight until the desired thickness is

achieved while in the pavement thickness mode. Then switching to the ACN mode, enter the allowable gross weight to obtain the ACN value. It is possible to develop a chart such as this because the parameters of subgrade modulus and the pavement thickness are already known. This reduces the variables to the relationship of pavement life and allowable gross weight. By relating ACN to gross weight, as in Figure A3-4, ACN can be utilized in place of gross weight on the abscissa of the Figure A3-5 chart. Each of these steps will be illustrated by utilizing data from the first rigid pavement example of Appendix 2.

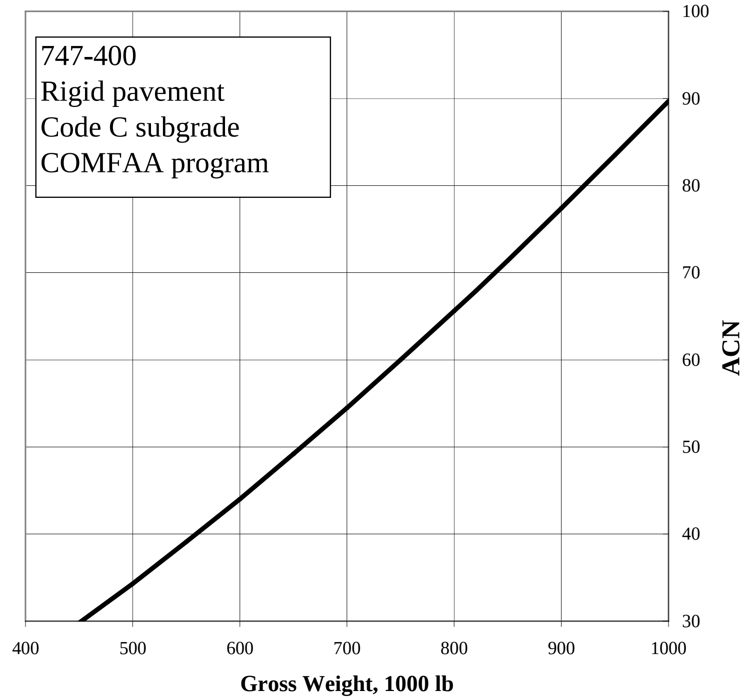

Figure A3-4. 747-400 Rigid Pavement ACN vs Gross Weight

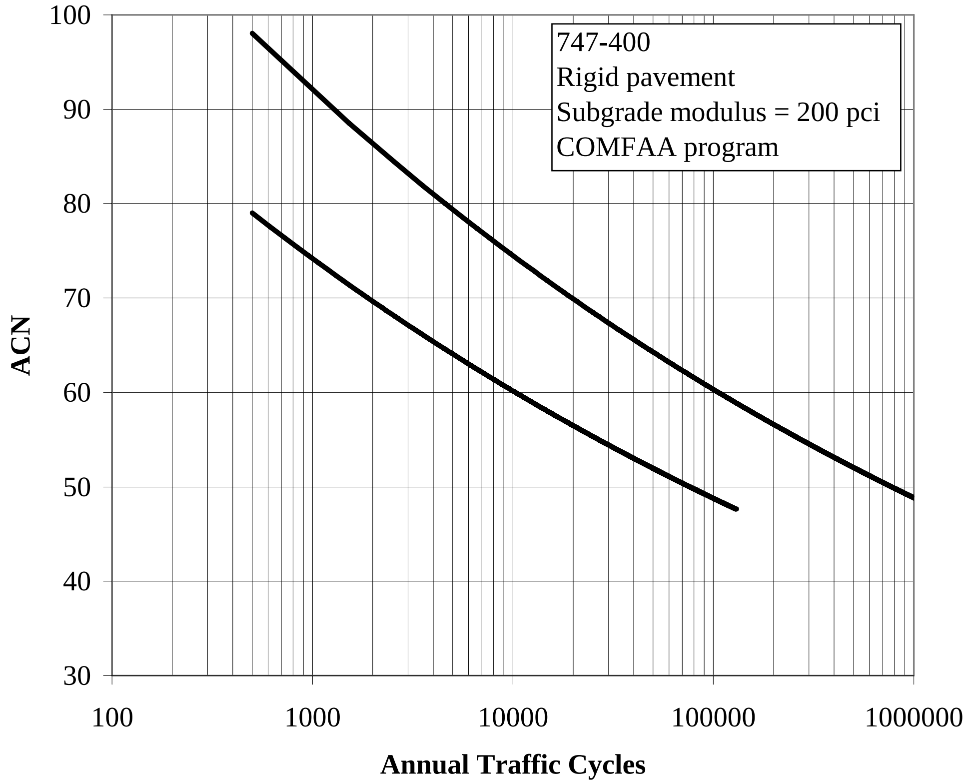

Figure A3-5. 747-400 Rigid Pavement Life versus ACN

Table A3-4. Data for Constructing Rigid Pavement Life Curves for B747-400

Annual Traffic Cycles	Load Repetitions (coverages) (P/C = 3.46)	T=14 gross weight (lbs)	T=14 ACN	T-16 gross weight (lbs)	T=16 ACN
500	2,890	910,000	78.6	1,063,000	97.7
1,200	6,936	871,000	73.9	1,015,000	91.6
2,400	13,873	827,100	68.8	962,000	85.0
3,000	17,341	813,500	67.2	947,000	83.1
5,000	28,902	783,900	63.8	913,500	79.0
11,410	65,954	741,000	59.0	865,000	73.2
20,000	115,607	714,500	56.1	835,000	69.7
50,000	289,017	675,000	51.8	786,250	64.1
86,500	500,000	654,000	49.6	760,000	61.1
129,750	750,000	638,500	48.0	742,000	59.1

3. It is now possible to relate the effects of gross weight, ACN, and pavement life by combining these two charts, as shown in Figure 5-6. The left hand side of this figure is the chart of Figure 5-4, while the right had chart is that of Figure 5-5. It can now be seen that the rating of PCN 59 RCWT on a 14 inch pavement equates to 11,410 traffic cycles per year of a B747-400 at 741,000 pounds.

4. The line for a thickness of 16 inches in Figures A3-5 and A3-6 shows how pavement life is increased by the addition of two inches of concrete. This line is included, not to imply that an overlay of two inches is recommended, but to only show the effect of increased thickness. It can be seen that the 16-inch pavement will accommodate a B747-400 with a gross weight of 865,000 pounds. Alternately, at a gross weight of 741,000 pounds, the 747-400 can be accommodated on the thicker pavement to about 135,000 traffic cycles. Not shown directly in Figure A3-6 is that a 15 inch pavement (one additional inch) will accommodate 39,000 annual traffic cycles of a B747-400 at 741,000 pounds.

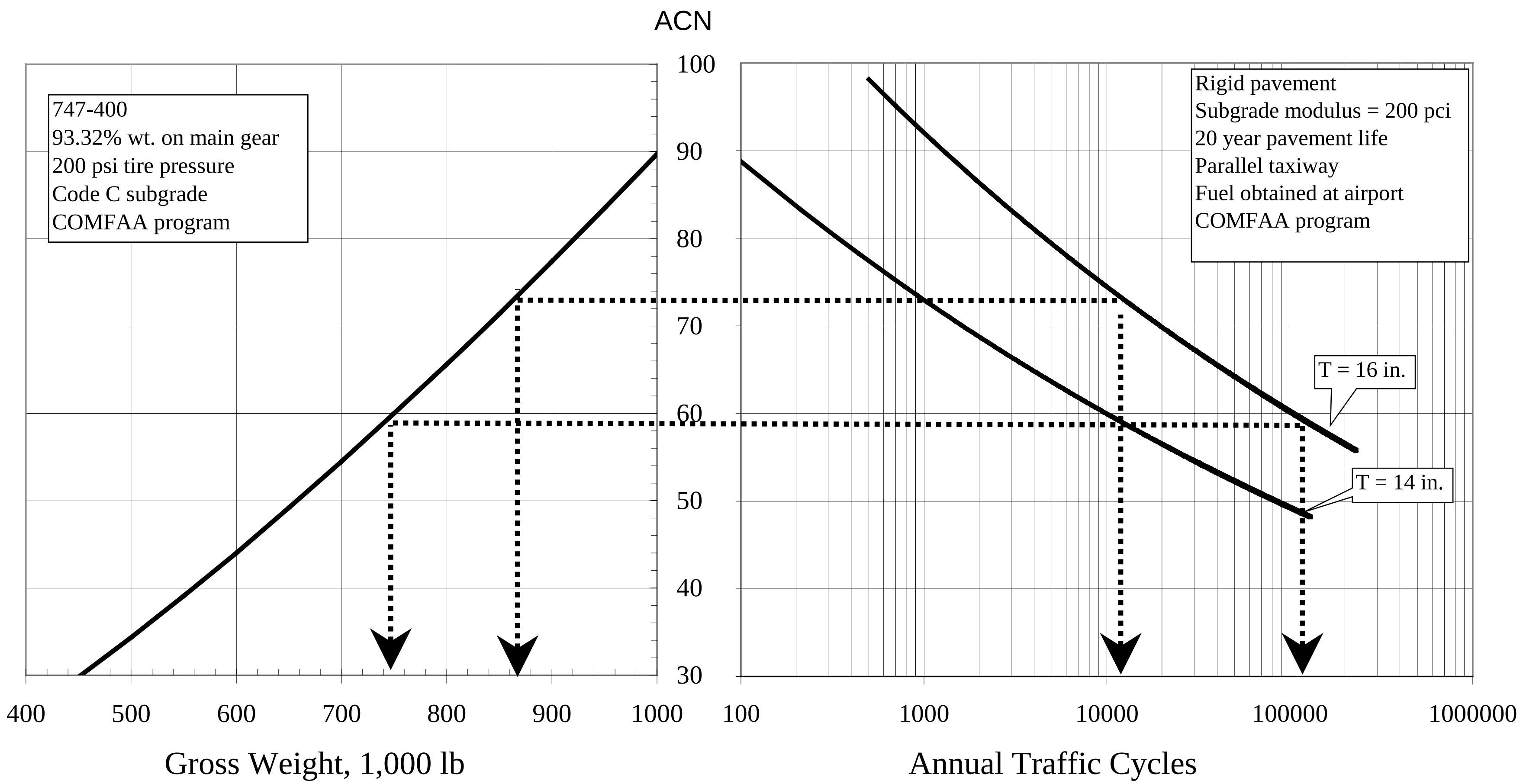

Figure A3-6. 747-400 Rigid Pavement Life

b. Rigid Pavement Overload Illustration 2. This example will illustrate the effect of ICAO allowable overloading in which the ACN is no more than 5% above and PCN and the number of traffic cycles does not exceed 5% of the total annual traffic.

Table A2-5 is repeated here as Table A3-5, but with a new airplane added to the traffic mix with an ACN that is 5% above the rated PCN of 59/R/C/W/T. The total annual departures, as shown in Table 4-4, is 15,200, of which 760 is 5% of the total. This amount is shown in Table A3-5. Normally in a calculation of critical airplane equivalent departures the W_2 wheel load would be listed as 35,625 pounds for a widebody airplane, but for the sake of illustration, the new airplane actual single wheel load is shown.

Table A3-5 Rigid Pavement Overload Example with New Airplane

Airplane	Operating Weight, lbs	Tire Pressure (psi)	ACN (R/C)	** P/C	Annual Departures	Load Repetitions
B727-200	185,000	148	55	2.92	400	2,740
B737-300	130,000	195	38	3.79	6,000	31,662
A319-100	145,000	173	42	3.18	1,200	7547
B747-400	820,000	200	68	3.46	3,000	17,341
B767-300ER	370,000	190	58	3.60	2,000	11,111
DC8-63	330,000	194	62	3.35	800	4,776
A300-B4	370,000	205	67	3.49	1,500	8,596
B777-200	600,000	215	77	4.25	300	1,412
A300-600R	354250	231	62	3.39	760	4,484

** Rigid P/C determined at 95% of gross load on main gear and at manufacturer's recommended operating characteristics for ACN calculation.

It is next necessary to determine the new total departures of the critical 747-400 airplane. To do so, Table A2-7 is shown here as Table A3-6 with the new A300-600R airplane included. As can be seen from this table, the number of 747-400 equivalent annual departures has increased to 12,761 from 11,410. The new equivalent departures are 12,761, which convert to 73,763 lifetime load repetitions. ($12,761 * 20 \div 3.46 = 73,763$). From the COMFAA program, the new allowable 747-400 gross weight is 735,000 lb, and the ACN at this weight is 58.3/R/C.

Table A3-6 Equivalent Annual Departures of the Critical Airplane

Airplane	Annual Departures	Gear Type	(R_2) Equiv. (2D) Departures	(W_2) Wheel Load	(W_1) 747-400 Wheel Load	(R_1) 747-400 Equiv.Ann. Departures
727-200	400	D	240	43,940	35,625	473
737-300	6,000	D	3,600	30,875	35,625	2,172
A319-100	1,200	D	720	34,440	35,625	687
747-400	**3,000**	**2D/2D2**	**3,000**	**35,625**	**35,625**	**3,000**
767-200ER	2,000	2D	2,000	35,625	35,625	2,000
DC8-63	800	2D	800	39,190	35,625	1,109

A300-B4	1,500	2D	1,500	35,625	35,625	1,500
777-200	300	3D	510	35,625	35,625	469
A300-600R	760	2D	760	42,067	35,625	1351
	15,960					12,761

The new recommended PCN would then be 58/R/C/W/T. Alternatively, the effect on pavement thickness can be seen by keeping the critical airplane gross weight the same at 741,000 pounds. The resulting required concrete slab thickness is 14.1 inches, which is a 0.1 inch increase.

APPENDIX 4. RELATED READING MATERIAL

The following publications were used in the development of this a. FAA Order 2100.13, FAA Rulemaking Policies, Department Federal Aviation Administration, and Washington, D.C. 20591.

b. AC 150/5320-6, Airport Pavement Design and Evaluation. This publication is available free of charge from the Department of Transportation, Section, M-442.32, Washington, D.C., 20590.

c. ICAO Bulletin, Official Magazine of International Civil Aviation, Airport Technology, Volume 35, No. 1, Montreal, Quebec, Canada H3A 2R2,. January l980.